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ICEBREAKING THEORY DEVELOPMENT
BY SEGMENTED MODEL TESTS:
REFINEMENT OF TECHNIQUE

VOLUME I

by

A. Godon
A. Nawwar

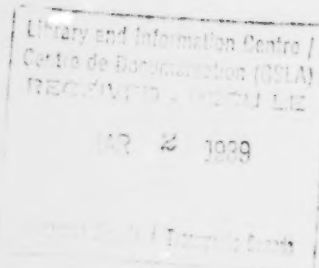
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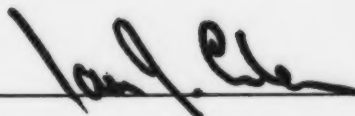
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Un sommaire en français de ce rapport est inclus avant la Table des matières.

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A handwritten signature in dark ink, appearing to be 'Janet Chen', is written over a horizontal line.



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17. Abstract This report describes the further refinement of a segmented model of the CCGS PIERRE RADISSON. The model has been developed to study the mechanisms of ice-breaking. It has the capability of tracing the movement of ice loads along the bow segments and measuring position, magnitude and direction of the ice load continuously during icebreaking. In this program the segment support system has been modified to improve the accuracy of the measurement. The segments and the data acquisition system were also modified. An extensive calibration program was designed to calibrate all segments and assess their accuracy. This included the development of a calibration rig and in-water calibrations. Ice tests were performed on three ice sheets varying in thickness and strength. It is shown that a level of segment accuracy has been achieved which warrants application of the technique to further investigations of icebreaking mechanisms. Tests also showed that ice load increases as the point of application moves aft into the shoulder region, with decreasing waterplane and flare angles. There appears to be a load increase by a factor of five between the stem segment and the shoulder segment. Friction factor was observed to vary inversely with the normal load under all conditions. Further study to define the friction phenomenon is required.			
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17. Résumé Ce rapport décrit les progrès réalisés sur le modèle réduit segmenté du brise-glace canadien PIERRE-RADISSON, qui a été mis au point afin d'approfondir le mécanisme de rupture des glaces. Grâce à ce modèle, il est possible de localiser la charge des glaces sur chacun des segments durant le déglacage ainsi que d'en mesurer l'amplitude et l'orientation de manière continue. Le dispositif d'appui des segments a été modifié pour une précision accrue des résultats. Les segments et la chaîne de mesure ont eux aussi été modifiés; de plus, un programme exhaustif a été lancé en vue de l'étalonnage des segments et l'appréciation de leur précision, comprenant l'étude et la réalisation d'un dispositif d'étalonnage et l'étalonnage du modèle dans l'eau. Des essais dans les glaces ont été faits dans trois couches d'épaisseur et de résistance variées. Les résultats montrent un niveau de précision de mesurage tel que l'on est justifié de retenir cette technique pour approfondir davantage le mécanisme de rupture. Les essais ont également permis de constater que la charge des glaces croît progressivement à mesure qu'on se déplace vers l'arrière dans une région caractérisée par des angles à la flottaison et des angles de dévers décroissants. Il a été constaté que la charge est multipliée par un facteur de cinq entre les segments no 1 à l'avant et no 3 près de l'épaule, et que le coefficient de frottement varie inversement à la composante normale de la charge, quelles que soient les conditions de charge. Une étude plus approfondie a été jugée nécessaire pour mieux cerner ce dernier phénomène.			
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SUMMARY

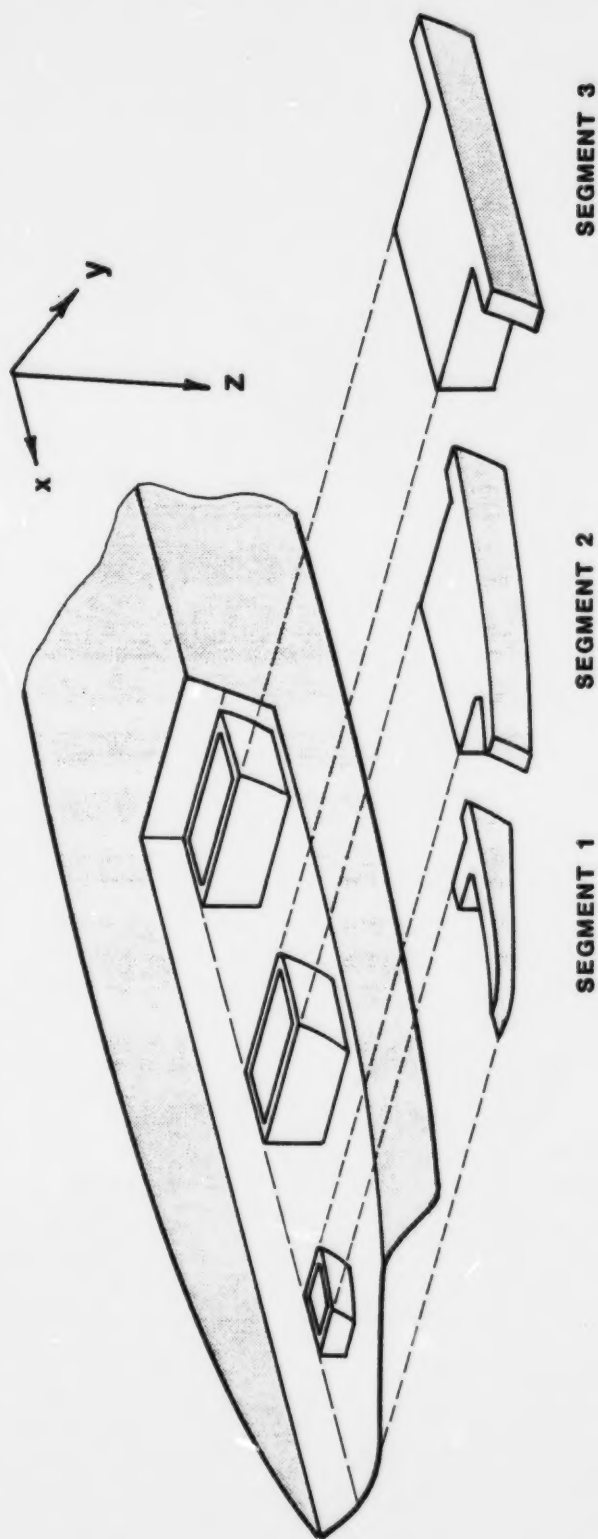
The use of segmented models to develop a prediction capability for ice resistance for icebreaking ships is an innovative approach which has been supported by the Transportation Development Centre during the past five years. Earlier reports reported by Nawwar and Howard in 1984, have been directed towards the technique development. This included the development of a rationale for segmentation, methods for physical segmentation of a ship hull model, for supporting the segment and instrumentation of each segment to measure the ice load in detail. The CCGS PIERRE RADISSON model hull was used as a basic hull for this study program. Figure 1 illustrates the overall segmentation plan of the model.

Preliminary tests were performed on the segmented model hull and have demonstrated that the technique could be used successfully to measure ice forces acting on three independent bow segments. These tests have also identified the need for some improvements and refinements which have lead to the present study.

The modifications performed on the model included the segment support system, the segment preload system and several structural modifications of the segments.

The segment support system was affected by misalignment between the load support or bearing surfaces and the transducers in the three principal directions of measurement; longitudinal, vertical and transverse directions. In order to improve alignment accuracy, a special jig was constructed for each segment. The jig defined the principal directions of measurement relative to the segment, and were used to ensure accurate machining of the bearing surfaces in three mutually perpendicular planes. This procedure minimized the misalignment of the segments with the bearing (or support) surfaces.

The segments were preloaded to ensure continuous contact with the load support surfaces. A compliant preloading system was found to be inadequate, and hence a stiffer pretensioning system was designed. The stiffness was established so that contact would be maintained during ice testing. However, the use of a stiffer system necessitated the measurement of the pretension load. Therefore, specially designed tension links were used for this purpose. The locations of the tension links were selected with the aid of Finite Element Modelling to determine the range of preload, examine constraints in mounting position and angle, and ensure that the maximum transducer load during testing would not exceed its rated capacity. The minimum and maximum preloads on all transducers were established and in some cases the adjustment range was as small as 5 N (~ 1 lb.).



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LEFT HAND COORDINATE SYSTEM WAS USED AS ILLUSTRATED

Figure 1 METHOD OF MODEL SEGMENTATION

The three segments were modified to accommodate the new pretension arrangement and facilitate segment assembly, disassembly, as well as adjustments during set-up and testing. The extent of modification varied in each of the three segments. Segment 3 was also structurally modified to reduce its mass and hence its inertial effects on measurement of ice loads.

The modifications described above have increased the total number of load measurement points. Figure 2 illustrates the number, type and designation of the various transducers, including tension links. (Observe the new lightened shape of segment 3). The load measurements made at each transducer have been labelled R, H or V depending on whether they were in the longitudinal, horizontal (transverse) or vertical directions; respectively. The numeric subscripts designate the segment number and the transducer number, respectively.

The segmented model instrumentation and data acquisition plan is described in Figure 3. All force components of segment loads measured by 28 transducers, total resistances, model speed and position were digitally processed and stored on disc. Only 25 transducer measurements and speed were backed up on magnetic tape recorder. The data acquisition software was modified to accommodate the increase in number of transducers.

From the transducer measurements on each segment, the external ice load was calculated. An iterative procedure was used to determine the position of the ice load centre on the model surface. This procedure was performed with the aid of a hull form interpolation program. The latter was essentially a cubic spline description of the hull offsets at various water lines. The offsets were taken from the lines plans and were, therefore, equally accurate. The hull form representation in this form was an efficient way to determine the coordinates of any point on the hull surface as well as hull angles at this point. It should be noted that while this representation is very efficient and practical, it only represents the lines plans. A larger number of offsets will be required for increased accuracy, particularly if the hull has an "S" shape and near the shoulders where the angles are rather small and the errors can be high. Also it should be borne in mind that the actual hull form of the model is subject to deviations from the lines plans. These deviations are minimum for model hulls produced on numerically controlled model making machines, but can be significant for models where the hull has been manually faired.

The data analysis algorithms have been used to trace the ice load along the bow segments; i.e. measure the position, magnitude and direction of the ice load continuously during icebreaking tests. The ice load is defined in terms of a component normal to the hull, a friction component, and a direction in the tangent plane at the point of load along which the friction force acts.

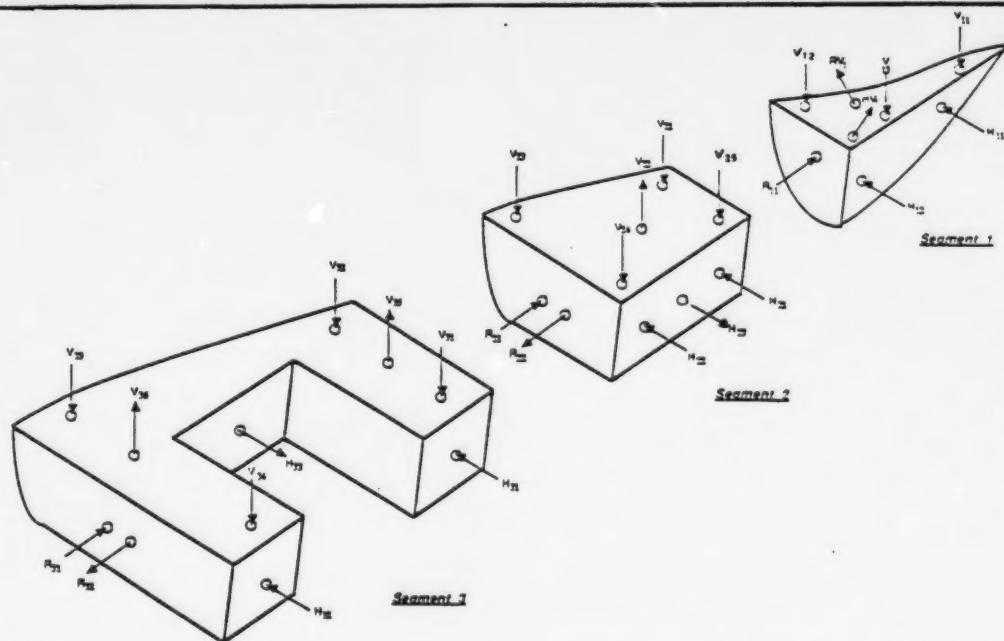


Figure 2 SEGMENT SUPPORT SYSTEM

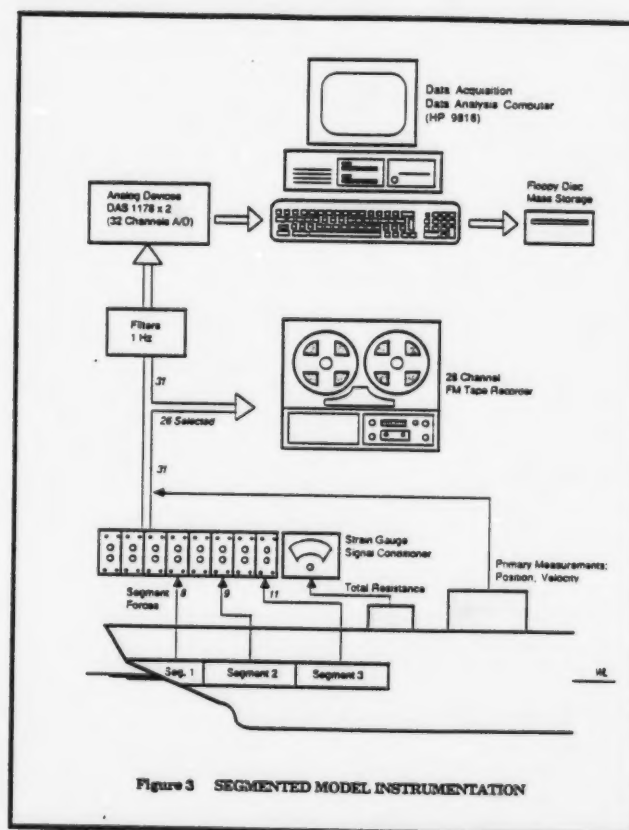


Figure 3 SEGMENTED MODEL INSTRUMENTATION

A comprehensive calibration program was undertaken at several levels to ensure that the system was fully calibrated and debugged and to eliminate, or minimize and quantify uncertainties at each level of model instrumentation. The model calibration plan may be outlined as follows:

- Transducer Calibrations: to determine transducer conversion factors, linearity and hysteresis.
- Internal Segment Calibrations: to assess the interaction between the transducers and the segment.
- External Segment Calibrations: to assess segment response to normal and frictional loads both in-air and in-water.
- Floating Model Calibrations: to determine segment responses to model motions, i.e. roll, pitch, and heave and also the effects of open water hydrodynamic loads.

The calibration of transducers was performed using dead weights and incremental loading. Most compression load cells were built in 1983 and had to be re-calibrated. The new calibration factors differed slightly from earlier calibrations and on the average were 2.3% higher. All transducers have shown excellent linearity with very low hysteresis. An attempt was made to measure the cross sensitivity of the load cells to sliding friction. It was observed that the maximum load fluctuation which occurred during sliding was independent of the load and was an average of less than 0.5% of the rated load.

Internal calibrations were performed to examine the response of compression load cells to an increase in pretension of one of the tension links in each segment. Since the net result of external loading is nil, the increase in tension should be counterbalanced at other segment support points and the changes should be in equilibrium. The internal loading was applied by increasing or decreasing the preload on tension links individually.

External calibrations were carried out using a built to-purpose calibration rig. The rig is illustrated schematically in Figure 4 and photographically in Figure 5. This rig was capable of measuring the applied external load components at a preset contact position and angle. The calibration procedure for all segments was applied in-air and in-water. The applied load was measured as well as the transducer responses. A total of 36 calibration points were selected on the three segments which extend over the entire segment lengths between stations 7 1/2 and 10 1/2 and between the 24 ft and the 16 ft waterlines. At each calibration position the hull interpolation program was used to generate the coordinates and hull angles. Accordingly the calibration rig set-up parameters were also calculated. At each calibration position two to six loading steps were applied to the segment and the transducer outputs recorded.

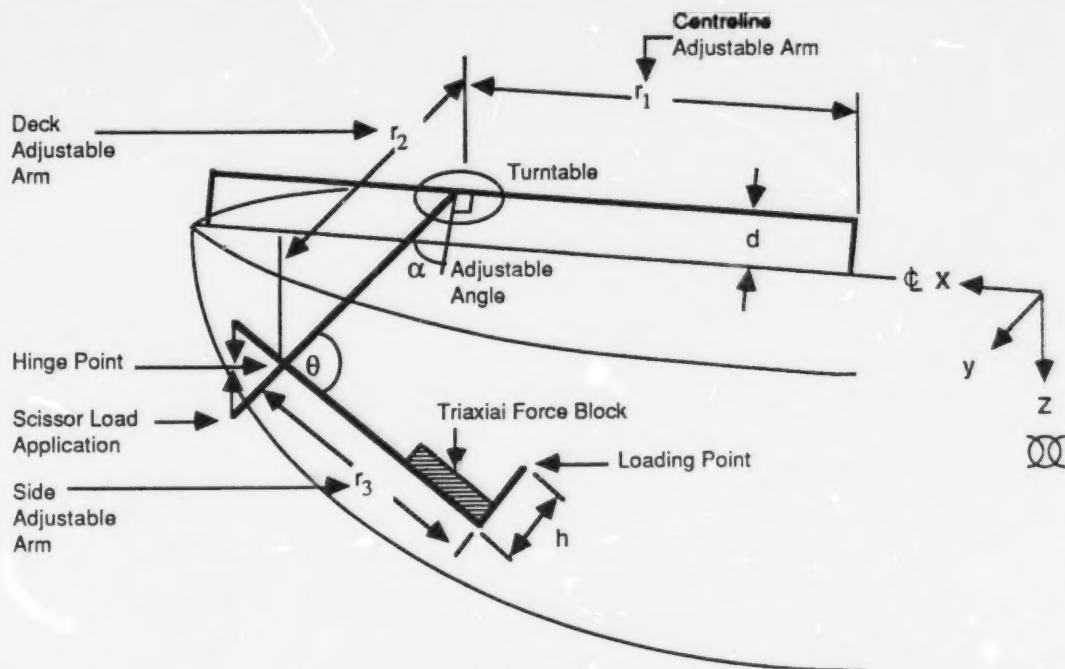


Figure 4 CALIBRATION RIG

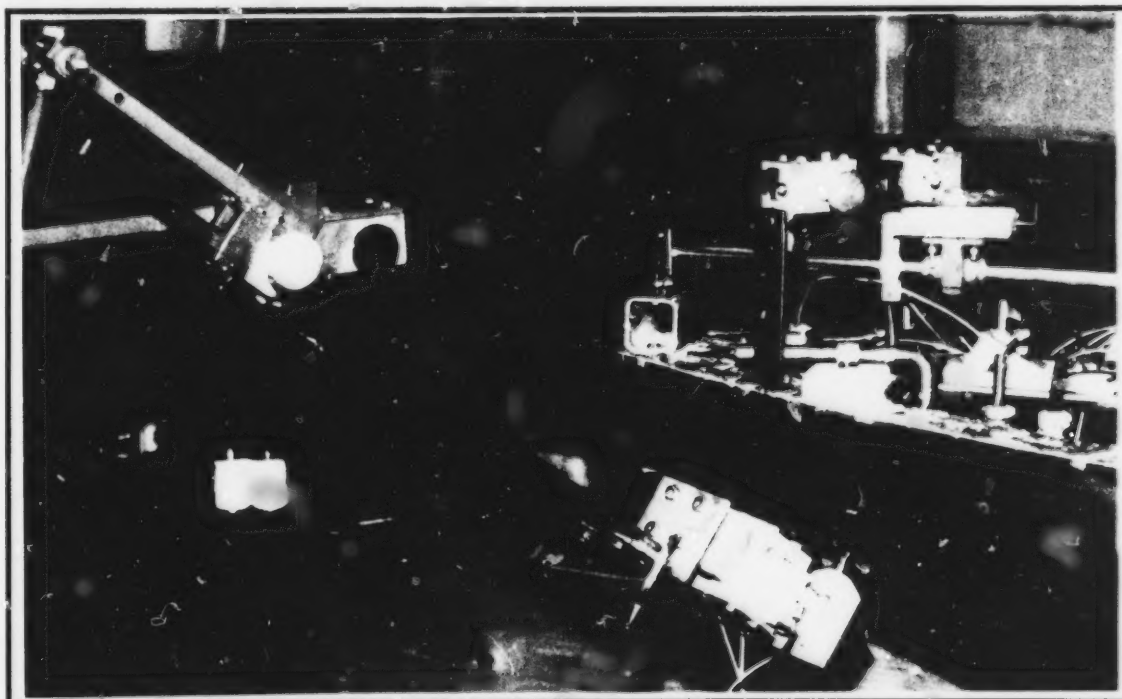


Fig 5 THE CALIBRATION RIG APPLYING A LOAD TO SEG. 1

The latter were used to calculate the applied load using the data analysis algorithms, and to compare the calculated load to the applied load. A typical calibration test data sheet is reproduced in Figure 6. To assess the segment nonlinearity, special tests were performed by stepped loading up and down for all three segments.

The results of these internal and external calibration tests on the three segments may be summarized as follows:

- a) Segment 1: behaves reasonably well except in the vertical direction where it tends to overpredict the force. After applying a correction to the vertical force the normal force could be predicted within 3% on the average. The overall response of Segment 1 was good.
- b) Segment 2: has shown a reasonable response, however the interaction between the load cells is quite complex, since removal of one load cell had significant effect on the results. The random errors for segment 2 were a little higher than expected. For instance, standard deviations of 19% in the longitudinal and 15% in the vertical direction were observed. It should be noted that random errors in the transverse direction were much better: the standard deviation was 1 N.
- c) Segment 3: which is the shoulder segment was also well behaved in general. However, due to the small waterplane and flare angles, the resolved forces in the longitudinal and vertical directions were generally very low and the horizontal (transverse) effects were dominant. Also the relative errors in these directions were high as may be expected due to the low magnitude of the resolved forces and low friction factor of the hull surface as tested. The overall response of the segment was good.

During the course of the experiments, it was suggested that the calibration rig itself could be a source of error. The rig was put together with very limited resources and time. As a result it has some inaccuracies in the joints and a relatively compliant structure due to its dimensions. Therefore, a special experiment was carried out to isolate the errors due to the calibration rig alone. The results of this experiment have indicated that, indeed, the calibration rig contributes some error and may be responsible for the deviation of error as well. However, unless the calibration rig can be tested in the exact configuration used at each calibration point, it is not possible to uncouple the calibration error from the segment error. Segment errors were due to misalignment of transducers, dimensional inaccuracies, cross sensitivities of transducers, etc.

In general, the overall performance of the segments was acceptable. An indepth error analysis indicated that most of the errors were spread around a constant mean with a constant variance.

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NOV 17 SEGMENT NUMBER 3 FILE NAME POS_46
 CALIBRATION POSITION 46

TRANSDUCER	READING (N)
R-31	2.65
R-32	.39
H-31	18.12
H-32	-.35
H-33	1.18
V-31	-5.08
V-32	22.49
V-33	.70
V-34	-1.06
V-35	1.42
V-36	.59
T'V	9.82
T'L	-2.74
NOR	26.28

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	3.56	3.04	-15.	-.5
Y	19.39	18.95	-2.	-.4
Z	20.15	19.07	-5.	-1.1

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -6.70 X PLANE
 C2= 13.41 Y PLANE
 C3= -12.22 Z PLANE

LOCATION	APPLIED	MEASURED	ERROR
:X=	1.613	1.607	-.006 m
Z=	.027	.021	-.006 m
WATERPLANE ANGLE	18.	18.	-1. DEG
FLARE ANGLE	27.	26.	-1. DEG
TOTAL FORCE	28.188	27.049	-4.0 %
NORMAL FORCE	26.279	25.187	-4.2 %
FRICTION FACTOR	.388	.392	
FRICTION FORCE	10.198	9.862	-3.3 %
FRICTION DIRECTION	106.	107.	1. DEG
FROM THE HORIZONTAL			

Figure 6 CALIBRATION TEST SHEET

The nonlinearity and hysteresis observed in the segments were well within the limits of the random errors observed during the segment calibrations and it was concluded that they likely arise from the same sources. Without applying any correction factors, the segments can measure normal ice force to within 10% or less on the average. The ice friction force can be measured to within 25% on the average (consider the low friction factor and magnitude of friction force). The position of the force can be determined quite accurately by segments 1 and 2 to within ± 0.02 m in the longitudinal direction and ± 0.005 to 0.010 m in the vertical direction. Segment 3 position fixing was less accurate and the coordinates of longitudinal and vertical positions could be obtained with ± 0.03 m and 0.02 m respectively. The direction of friction is accurate to within ± 15 degrees for a friction coefficient of 0.20 or higher.

Floating model calibration tests were conducted to measure the segment responses to heave, pitch and roll with a stationary model as well as the responses during open water towing at various speeds. The transducers were found to be least sensitive to heave motion, while the vertical transducers were the most sensitive to all motions especially in Segment 3. Typical sensitivities were of the order of 4 N/deg for pitch, 0.6 N/deg for roll, and 0.2 N/mm for heave. However, the segment responses were mostly negligible during open water towing and were typically less than 1 N.

Three ice sheets were tested having thicknesses and strengths of 20 mm/ 35 kPa, 27 mm/ 25 kPa, and 47 mm/ 30 kPa. The model speed was varied in the range of 0.10 to 0.66 m/s which corresponds to a full scale range from 0.9 to 5.7 knots. During testing the model was fixed to the towing carriage and not permitted to pitch, heave or roll. Yaw was also eliminated by a yaw restraint arrangement at the stern of the model.

The analysis of the transducer measurements, to obtain the position of ice load, its magnitude and direction, was performed for all tests. Figure 7 is the result of a time history analysis on ice loads on Segment 2 during a typical run. The analysis was performed with a minimum force cut-off applied to the total force. This eliminated errors associated with low levels of load. The cut-off levels for Segments 1, 2 and 3 were 5 N, 8 N and 12 N, respectively. This cut-off limit appeared to be proportionate to the segment weight. Hence, for future generations of segmented models lighter segment weights will be desirable.

It should be noted that several types of tests were performed including:

- a) New Sheet test (NS): a standard icebreaking test run.
- b) Channel Widening test (CW): a second run with the model centerline offset to widen the channel on the port side, which is also the segmented side.

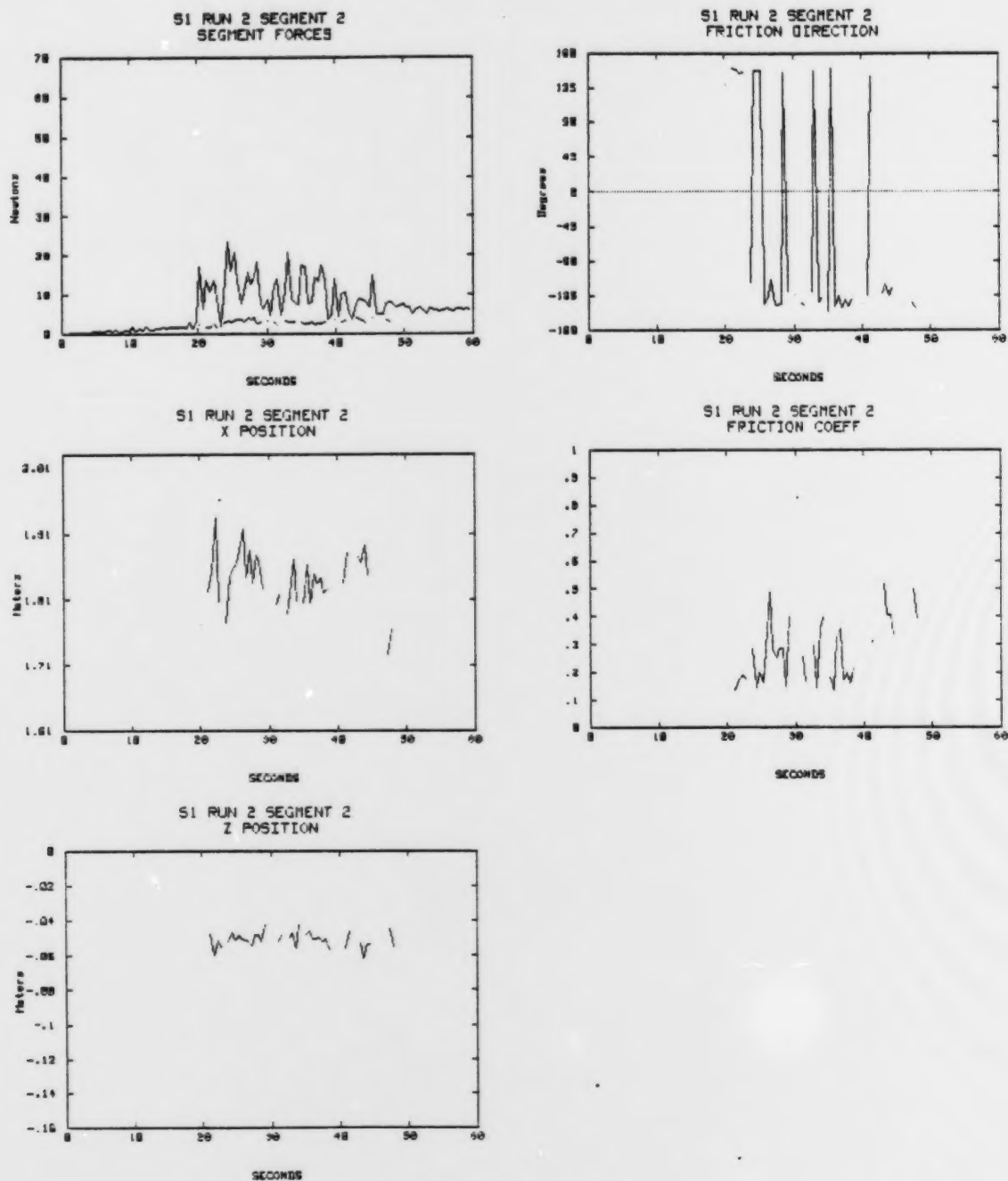


FIGURE 7
TYPICAL PLOTS OF ICE LOAD ANALYSIS
($h = 27 \text{ mm}$, $V = .45 \text{ m/s}$ $\sigma_f = 25 \text{ kPa}$)

- c) Segment scraping test (SS): in which the model is rotated at a yaw angle of about 25° and pushed by the carriage and moved down the channel so that the ice edge scrapes segment 2 at stations 9 to 9.5.
- d) Ice Impact test (II): in which ice pieces were pushed or dragged manually along the hull segment at different locations. This test was rather qualitative in nature and the results were reported without much discussion.

One of the major concerns registered in Phase I tests was the problems associated with segment lift off, and large zero offsets of transducers during ice testing. This led to the modification of the segment support and preloading to its present form. Therefore, one of the main criteria for evaluation of the present system was the elimination of these concerns. The results have been examined to evaluate the success in this endeavour and it was observed that:

- a) Segment lift off has been completely eliminated. All transducers could be preloaded properly and remained active during the entire test period in ice.
- b) A significant improvement in zero offsets has been achieved. Close to 60% of all transducers exhibited excellent behaviour and negligible offset (less than 0.5 N for a 100 N cell) compared to only about 4% in Phase I tests. The poor performing transducers have been almost eliminated to about 4% compared to 20% before modification. Some offsets may be expected due to the possibility of minute shifting of the segments under load. It should be noted that 4 N offset on a 100 N transducer is high but corresponds to a segment shift of ~0.5 micron, which is an insignificant quantity.

Therefore, the first observation one can make is that the modifications, as implemented, have been successful in eliminating and minimizing major problems encountered in the first phase of the program.

From the analysis of time histories from level ice tests and channel widening tests under similar conditions, it has been observed that the normal forces measured on each segment increased with increasing speed, ice thickness as well as segment position. Figure 8 illustrates the variation of normal force per unit length of the segment (to normalize the effect of segment length) with speed and thickness.

Further analysis of data to examine the effects of various hull parameters on the normal force and its correlation with other variables. Three test runs were selected for that purpose representing thin ice (27 mm/25 kPa) and thicker ice (48 mm/30 kPa) and tested at different speeds of 0.14, 0.22, and 0.3 m/s. The time histories for the normal force were scanned and the ice load was defined for maximum occurrences only.

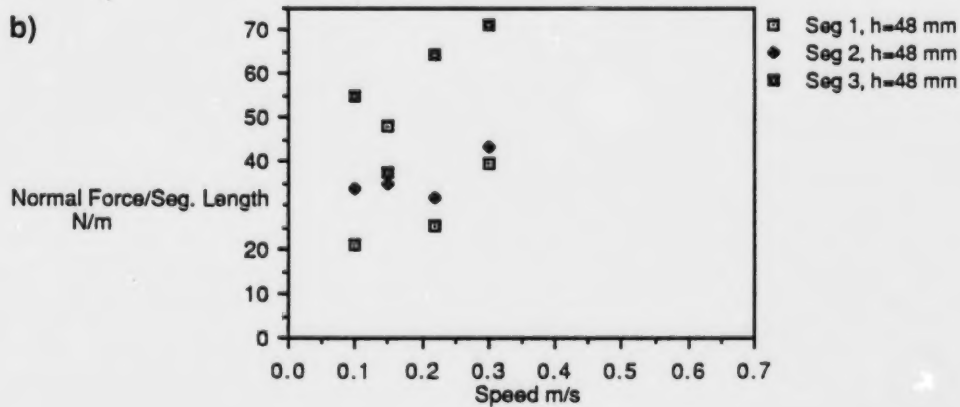
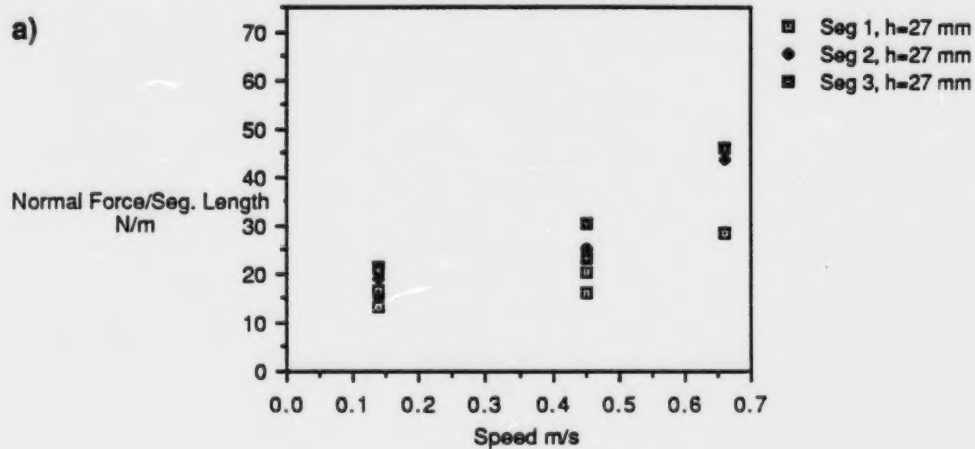


Figure 8
Normal Force per Unit Segment Length; a) h=27 mm; b) h=48 mm

These maximum occurrences were used to examine the possible correlations.

Figure 9 illustrates the variation of the normal force along the hull. It is evident that the lowest normal forces occur on Segment 1 at the forward section of the bow. The force increases progressively moving aft through segments 2 and 3. The force increased by approximately a factor of five over this traverse. The same trend and almost the same rate of increase of force were observed in thin ice but with lower forces. There also appears to be well defined upper and lower bounds on the data which confirm the trend of variation and exhibit the commonly observed scatter in ice force measurement.

The vertical position of the normal ice force did not vary significantly with longitudinal position nor load. However, for thick ice the ice force on Segments 1 and 2 acted at a depth of approximately half the ice thickness below waterline. Where as in Segment 3 the position of load was predominantly 10 to 15 mm lower than in Segments 1 and 2. This indicates a change of the mechanism of icebreaking on Segment 3. In thin ice, this change occurred earlier on Segments 2 and 3. It should also be noted that the scatter in the vertical position was generally low, as may be observed in Figure 10.

Since the hull angles vary along the length of the waterline, plots of the variation of the normal force with waterplane angle as well as hull flare angle were produced for the three cases; Figures 11 and 12. It is seen that as either of these angles decrease, the force increases. There is clear overlap between data from Segment 1 and Segment 2 with the same hull angles. It should also be noted that the force seems to be less sensitive to the hull flare for angles greater than 30°; this sensitivity appears to be tripled for lower hull flare angles. The load sensitivity to waterplane angle appears to be linear.

The friction coefficient corresponding to maximum force occurrences was observed to be fairly constant on Segments 2 and 3 at 0.08 to 0.15. This was significantly lower than the 0.10 to 0.25 average over the entire time history. For Segment 1 the friction coefficient varied in a wide range from 0.02 to 0.6. Figure 13 illustrates the variation of friction coefficient with normal force maximum occurrences, while Figure 14 is for all normal force data.

It should be noted that there is a reverse dependency of the friction factor on the normal load. This agrees with studies performed on the ice friction phenomenon. It is also noted that in the higher end of ice force the friction factor converges to an average of 0.1, which is more or less the expected value for the model tested. As the force decreases, the friction factor increases and the scatter also increases. At lower normal loads, it is recognized that the friction force will also be small and the errors in measurements will be significantly higher.

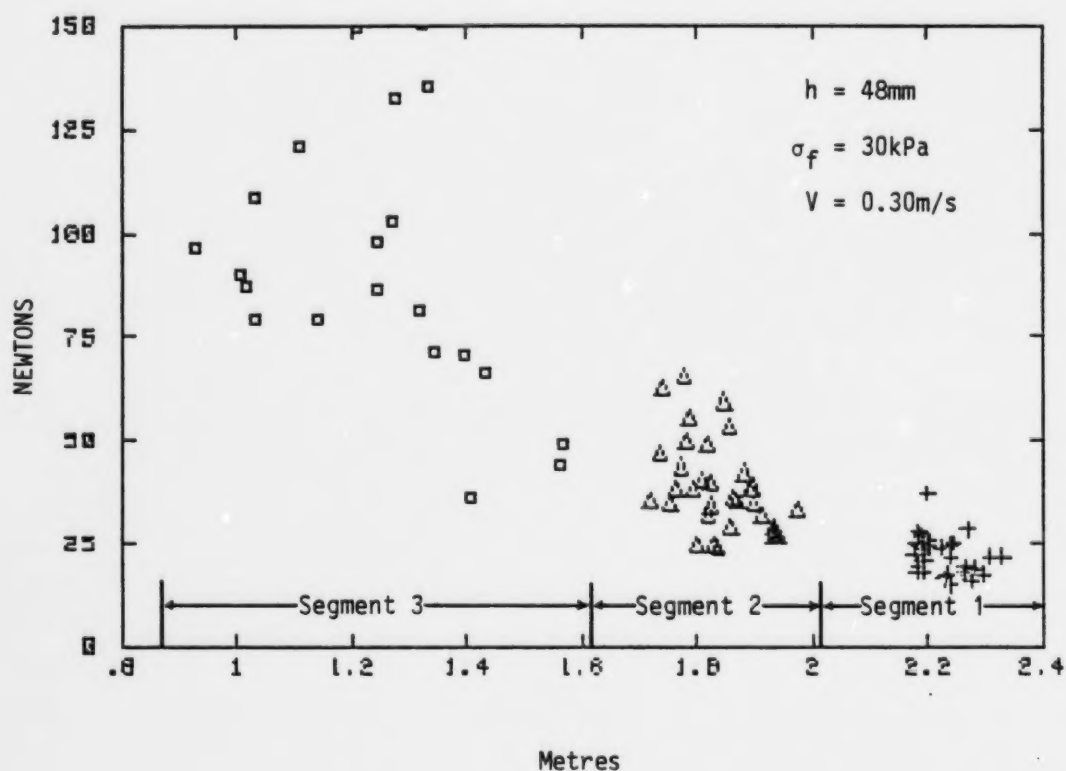


Figure 9 Longitudinal Position of Maximum Normal Forces During Test S32

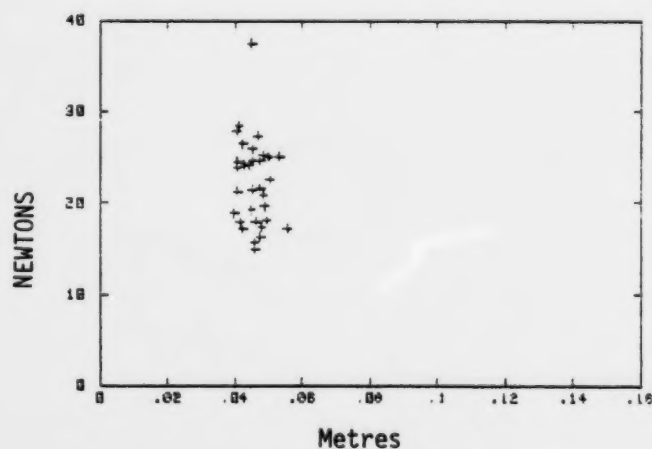


Figure 10 Vertical Position of the Maximum Forces on Segment 1 for Test S32
 ($h = 48\text{mm}$; $V = 0.30\text{m/s}$; $\sigma_f = 30\text{kPa}$)

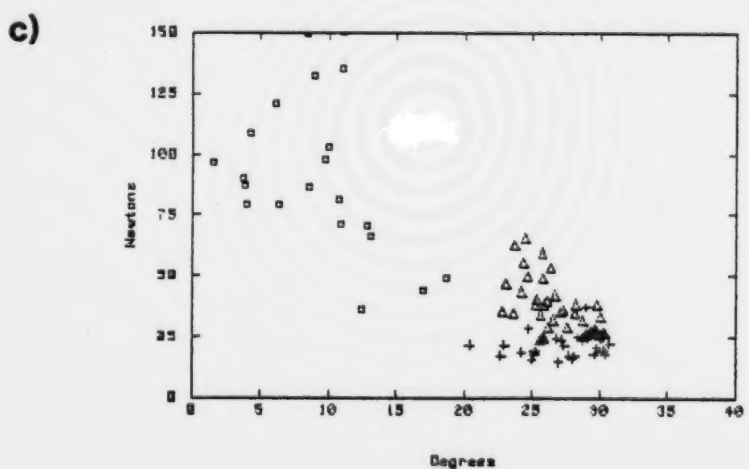
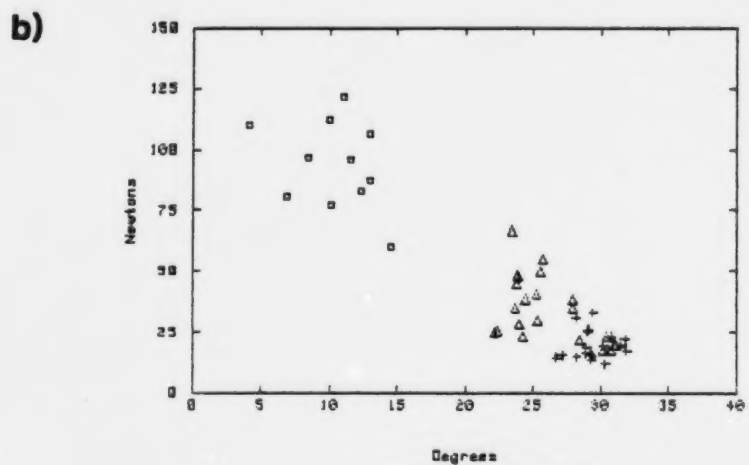
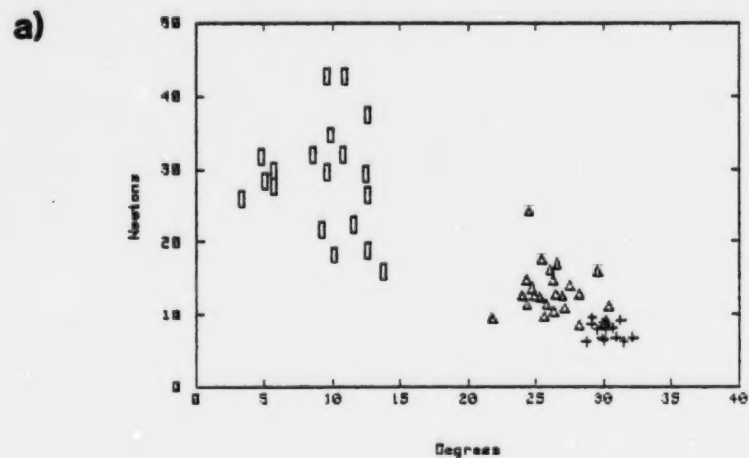
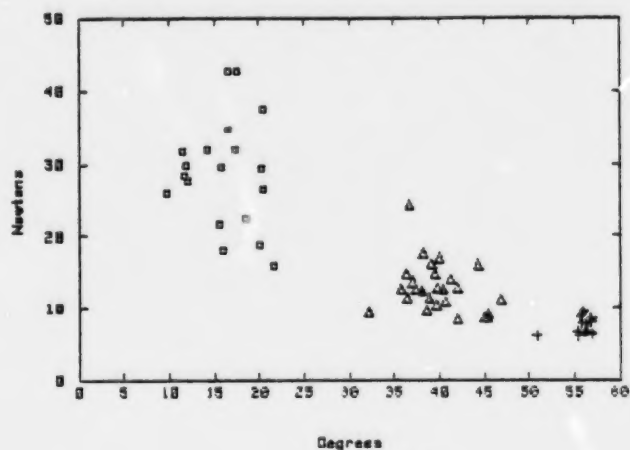


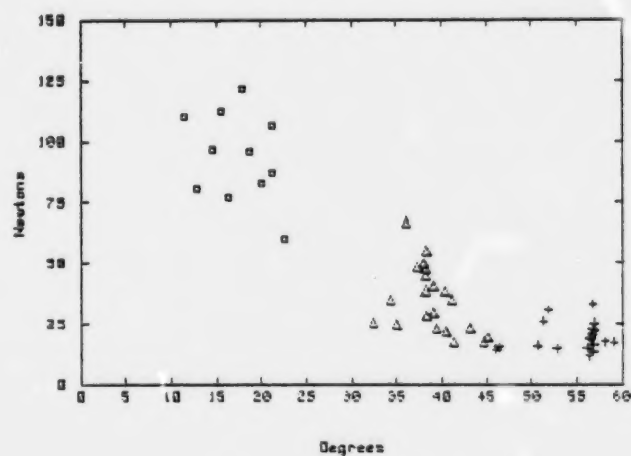
Figure 11 WATERPLANE ANGLES AT NORMAL FORCE MAXIMA FOR TESTS a) CW5, b) CW9, c) S32.

a)



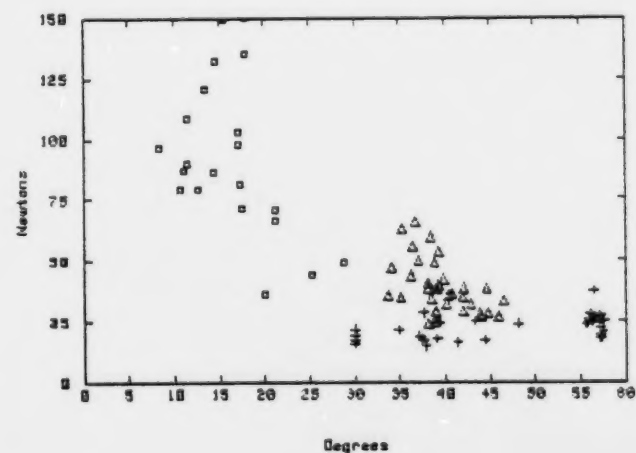
$h = 27\text{mm}$
 $\sigma_f = 25\text{kPa}$
 $V = 0.14\text{m/s}$

b)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0.22\text{m/s}$

c)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0.30\text{m/s}$

**Figure 12 HULL FLARE ANGLES AT NORMAL FORCE MAXIMA
 FOR TESTS a) CW5, b) CW9, c) S32.**

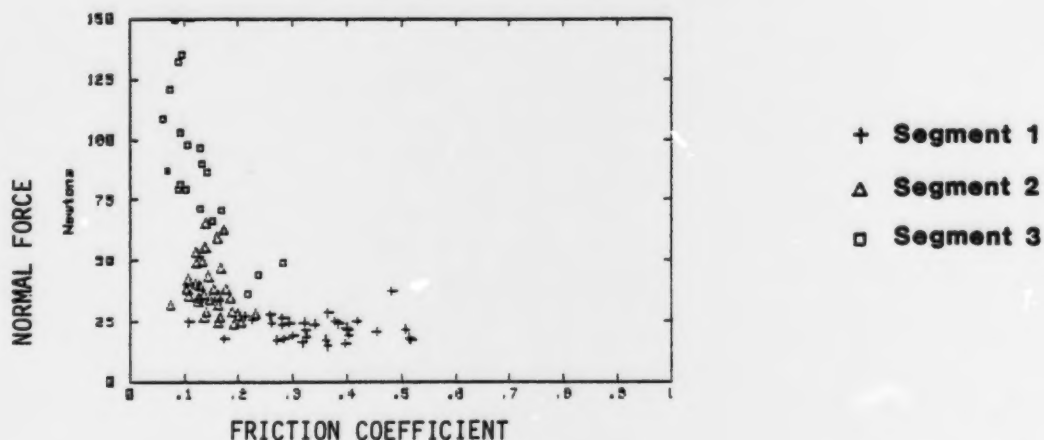


Figure 13 FRICTION COEFFICIENTS AT NORMAL FORCE MAXIMA DURING TEST S32 ($h = 48\text{mm}$, $\sigma_f = 30\text{kPa}$, $V = 0.30\text{m/s}$)

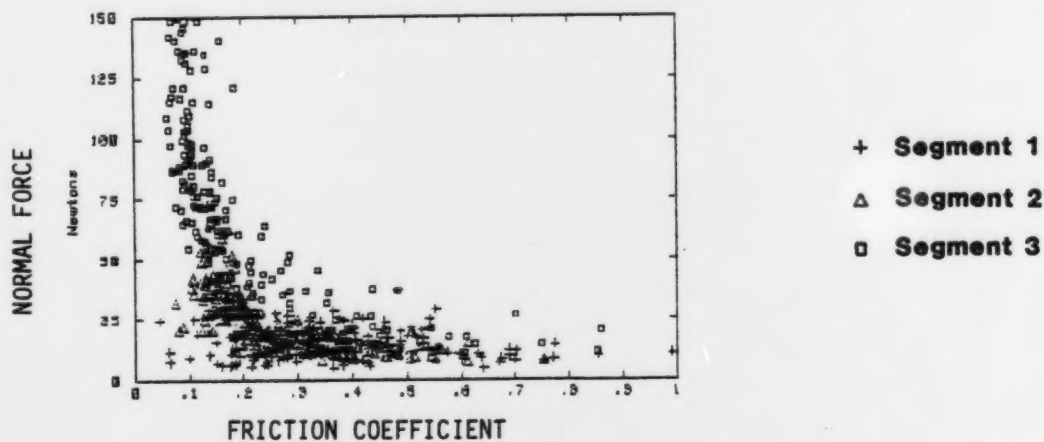


Figure 14 FRICTION COEFFICIENTS AT ALL NORMAL FORCE MEASUREMENTS DURING TEST S32 ($h = 48\text{mm}$, $\sigma_f = 30\text{kPa}$, $V = 0.30\text{m/s}$)

Finally, a correlation was made between the time histories and video observations to verify the types of physical events which correspond to the observed maximum loads on each segment. There was a definite correlation between the video observations and the time histories. On Segment 1, maximum loads occurred at the moment of cusp cracking or immediately following this event. Therefore, these maxima are clearly associated with icebreaking. On Segment 2 the peaks were very sharp (0.5 - 0.9 seconds duration) and corresponded to ice fracture and beginning of turning. Cusp sliding and slapping up against the hull appeared to be minor force events. On Segment 3 the physical events were much less discernible.

Based on the results of the present experimental program, the following conclusions may be made:

1. The problems of the segment support system have been resolved by using a stiffer preloading system. As a result the segments can now be accurately preloaded so that segment lift off does not occur during the ice testing. The stiffer preloading system has also decreased the segment movement during testing, thereby reducing the zero offsets. The bearing surfaces on which the transducers act have been machined so that the error in load measurement is less than 1%.
2. The calibration rig which was built specifically to calibrate the segments lacks structural rigidity with the result being that the calibration rig is a potential source of error. Within these limitations segment correction factors and error bounds have been determined from the calibration results. Segment linearity and hysteresis are less than the overall segment error and are most likely components of the random error associated with each segment. Repeat calibrations at the same point on each segment have confirmed the repeatability of the segment measurements.
3. Through segmentation the model has been developed into a working system which can measure ice loads, the frictional component of the load and its position and orientation on the segmented portion of the hull. A thorough model calibration has determined that for a 68% confidence limit the error bounds of the normal force are $\pm 13\%$ of the measurement depending on the segment and the error bounds of the friction force are $\pm 40\%$, $\pm 47\%$ and $\pm 14\%$ on Segments 1, 2 and 3 respectively. While the error bounds of the friction force seem high, the absolute value of the error is low due to the low magnitude of the friction force. The position of the force can be determined to $\pm 5\%$ of the segment length in the x direction and to within $\pm 7\%$ in the z direction. The friction direction can be determined within the error bounds of $\pm 15^\circ$ for friction coefficients greater than 0.2.

4. From the data collected during ice tests, it was found that the ice resistance on all three segments was highly dependent on ice thickness and on the model speed. The breaking pattern, determined by the frequency of the ice load maxima, was roughly proportional to the ice thickness. The magnitude of the maximum forces decreased with increasing waterplane angle and increasing flare angle. As well, a clear trend of exponentially increasing normal force with distance aft from the bow was observed. The friction coefficient exponentially increased as the normal force decreased. The direction of the friction was very erratic, but acted principally downwards on Segments 1 and 2 and slightly aft but still downwards on Segment 3.
5. The ice tests were carried out with the model rigidly fixed to the towing carriage so it was not necessary to correct the segment measurements for pitch, heave and roll. However, in separate static tests, the sensitivity of the model to heave, pitch and roll was recorded and correcting factors for the motions were determined. The model is sensitive to roll and pitch and the correction factors would be required if the model was towed freely.

Several recommendations may be made to improve the level of technology developed to date. However, with a working model of the CCGS PIERRE RADISSON, further applications of the model may be made in order to advance the state of our understanding of the icebreaking mechanisms and theory. Such applications will demonstrate the usefulness of the segmented model testing technique as a design tool for icebreaking ships. A more advanced stage of implementation addresses the next generation of modular segmented models. Specific recommendations in these three areas are stated below:

1. **Improvement of Technology:**

To improve the accuracy of the hull interpolation program, the model lines should be lifted from Segment 1 and added to the offsets already present in the routine. It is suggested that the data reduction algorithm be examined for improved and faster convergence on the solution. A new calibration rig using the design of the existing calibration rig but with stiffer components would eliminate the errors introduced by the calibration rig during the segment calibrations.

2. **Further Application of the Segmented RADISSON Model:**

a) The data collected shows a trend of increasing force with increasing distance from the bow and it is not possible to determine if the magnitude of the force decreases after the shoulder of the model (which occurs on Segment 3) has been passed. The modification of the model to include a fourth segment immediately preceding Segment 3 would allow measurement of forces on the parallel midbody and a more accurate description of the distribution of ice forces on the model.

b) A full complement of level ice tests should be performed to validate existing ice resistance theories such as Carter's and Arctec Canada Limited's computer model "Resistance of Ice" (RICE). The ice thickness, ice flexural strength, model speed and friction coefficient should all be included as parameters in the test matrix. Specific aspects to examine would be the variation of normal force along the hull. The usual assumptions that ice moves along the buttocks or waterplanes can be compared to the measured friction direction.

c) The effect of friction factor on the hull should be studied in detail. Results from tests conducted indicated an exponential increase of friction factor with decreasing normal force. It is of relevance to establish whether this is a phenomenon or an artifact of the test. To determine this, the friction factor can be varied by conventional means from 0.03 to 0.5 on the segments and ice test performed. The measurements can determine the dependent variables of the friction force and resolve any discrepancies in the measurement of the direction of friction.

3. Future Generation of Segmented Models:

a) In order to facilitate the use of segmented models in the design and optimization of hull forms, it is desirable and cost effective to have a modular type base model with detachable segments. The latter can be removed and replaced with other hull form variation without need to change the segment support system or instrumentation. Therefore, the first step would be to design a core hull with a special versatile instrumentation system which permits liberal changes of the hull form in a wide range but with a basic segmentation plan.

b) The advanced version of segmented model should then be implemented to study a hull form of interest such as the POLAR 8 icebreaker. This will permit the detailed evaluation of candidate hull forms in order to substantiate the merits of these forms and provide an insight for possible means of improvement of performance.

SOMMAIRE

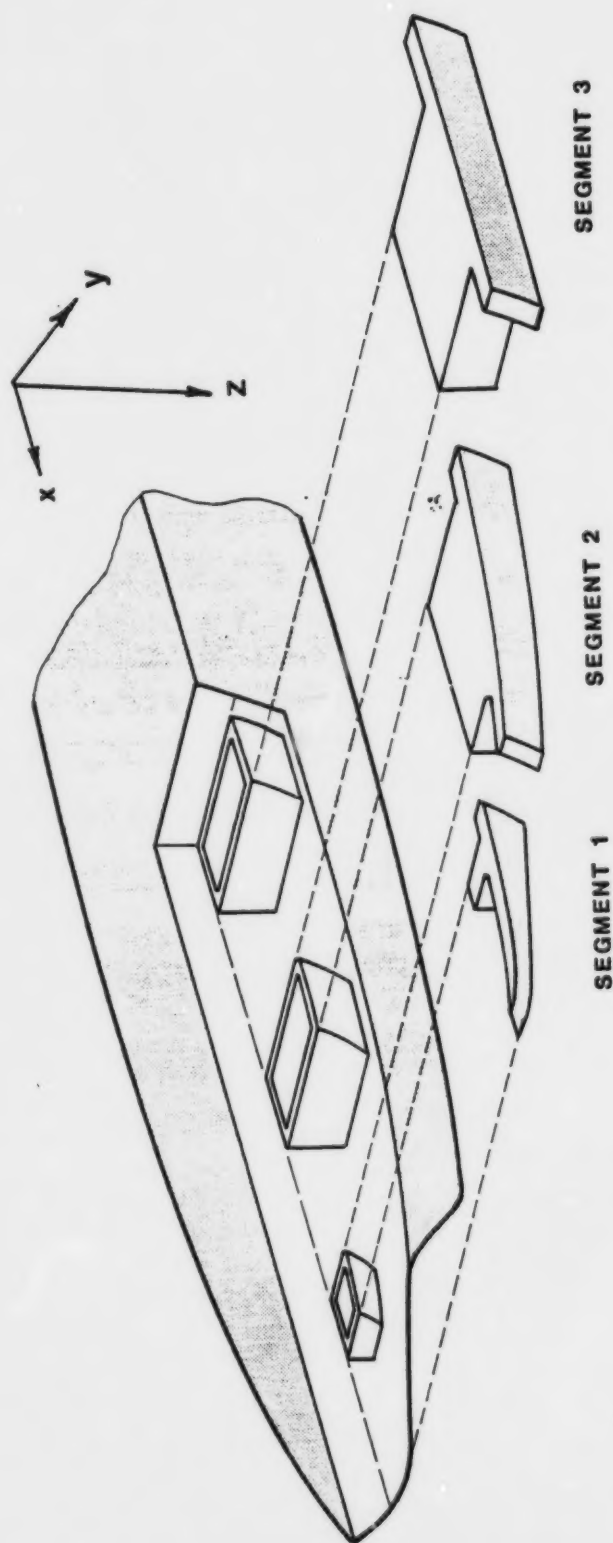
L'étude sur maquettes segmentées, technique novatrice de prévision de la tenue aux glaces des cargos brise-glace, a pu être mise au point au cours des cinq dernières années grâce au concours financier du Centre de développement des transports. Les travaux antérieurs, dont il a été rendu compte par Nawwar et Howard en 1984 (1), ont surtout visé le développement de cette technique, à savoir: la justification théorique de la segmentation, la méthode de découpage de la coque maquette, le dispositif d'appui des segments et l'instrumentation de ceux-ci dans le but d'obtenir des mesures précises sur la charge des glaces. C'est la maquette de la coque du brise-glace canadien PIERRE-RADISSON qui a servi aux fins de l'étude, et sa segmentation s'est faite selon la trame illustrée à la figure 1.

Des essais préliminaires sur la maquette segmentée ont montré l'utilité de cette technique pour mesurer les forces s'exerçant sur les trois segments sans lien les uns avec les autres. Ces essais ont en outre mis en évidence les perfectionnements et les affinements qui ont mené à la présente étude.

Les modifications décidées ont concerné le dispositif d'appui des segments, le dispositif de précontrainte de ceux-ci ainsi que leur structure même.

Le dispositif d'appui souffrait d'un mésalignement entre les surfaces d'appui et les capteurs, et ce dans les trois grands axes de mesure: longitudinal, vertical et transversal. Le besoin d'une précision accrue dans la définition des surfaces d'appui a mené à la réalisation d'un montage construit exprès pour chacun des trois segments. Ces montages qui définissaient les principaux axes de mesure par rapport aux segments ont permis l'usinage précis des surfaces d'appui, dans trois plans perpendiculaires, ce qui a réduit les mésalignements entre les segments et les surfaces sur lesquelles ils s'appuyaient.

Les segments ont été soumis à une précontrainte afin d'assurer la permanence du contact. Le dispositif élastique antérieur ayant été trouvé inadéquat, un nouveau dispositif a été conçu, d'une raideur telle que le contact puisse être maintenu même lors des essais dans les glaces. En revanche, ce nouveau dispositif a nécessité que l'effort de précontrainte soit connu, d'où la réalisation d'anneaux de précontrainte encastres et leur installation en des emplacements choisis d'après la méthode des éléments finis. Cette méthode a permis de déterminer l'étendue de la précontrainte, de reconnaître les contraintes de position et d'angle et de faire en sorte que les efforts maximums s'exerçant sur les capteurs en charge restent dans les limites prévues. Les valeurs de précontrainte maximales et minimales ont été déterminées à l'égard de chaque capteur, la plage de réglage s'établissant dans certains cas à une valeur très limitée: 5 N (1 lb environ).



La pont supérieur a été omis pour plus de clarté.
Les coordonnées illustrées sont de la main gauche.

Figure 1 Découpage de la coque en segments

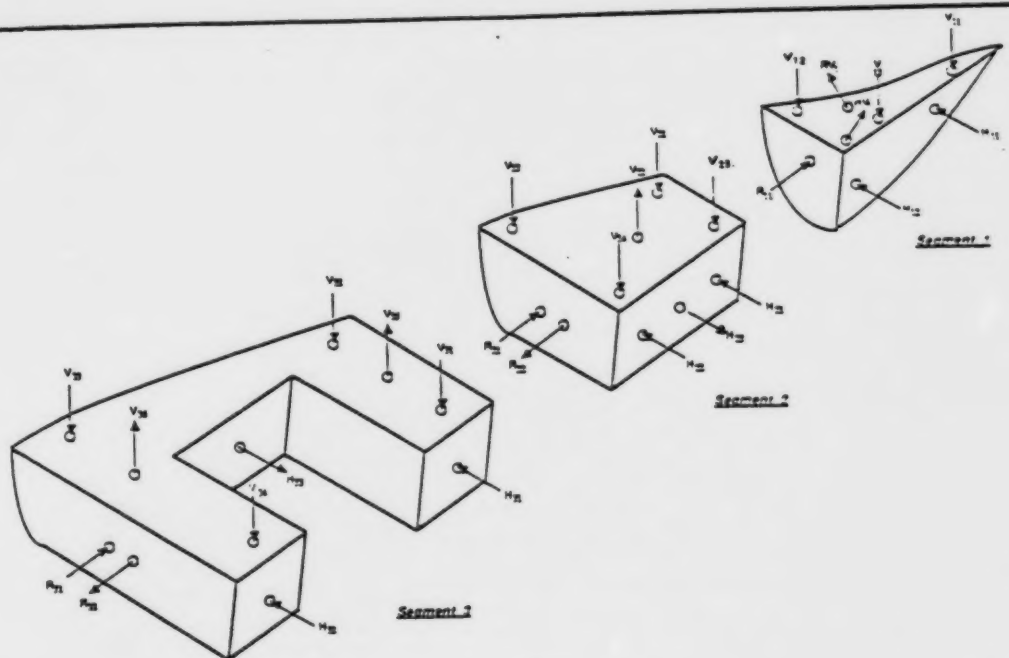


Figure 2 Dispositif d'appui des segments

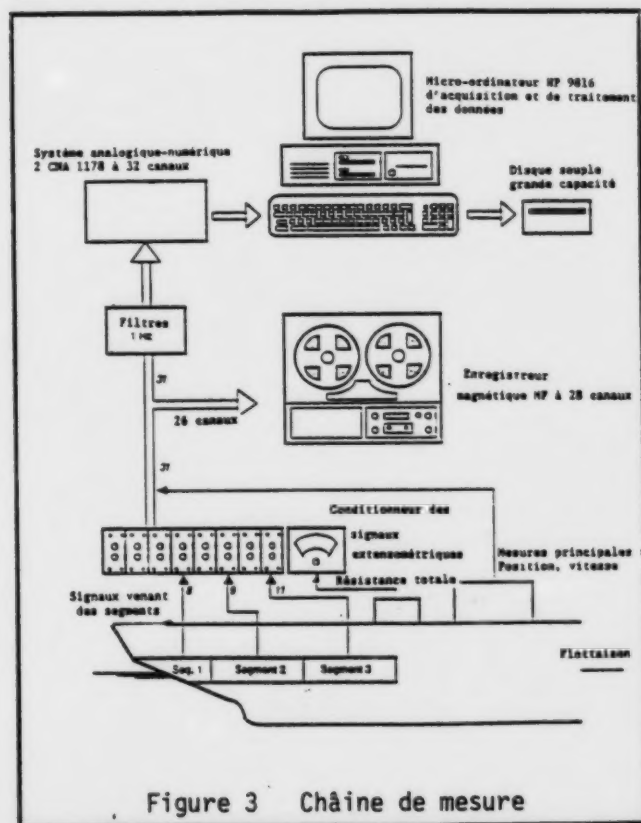


Figure 3 Chaîne de mesure

La forme des segments a été réétudiée afin de l'adapter au nouveau dispositif de précontrainte et de rendre plus aisées les opérations de montage et de dépose, ainsi que les réglages durant le montage et les essais. L'ampleur des travaux n'a pas été la même pour chaque segment. Le segment 3 a été en outre allégé de manière à réduire l'influence de l'inertie sur les résultats.

A cause de ces modifications, le nombre total de points de mesure a augmenté. La figure 2 montre la disposition et la désignation des divers capteurs et des anneaux de précontrainte (à remarquer, la nouvelle forme allégée du segment 3). A chaque vecteur a été accolée la lettre R, H ou V selon que l'effort se faisait dans l'axe longitudinal, transversal ou vertical, respectivement. Quant aux deux indices inférieurs, ils correspondent au numéro du segment et du capteur, respectivement.

La chaîne de mesure utilisée et l'organigramme d'acquisition des données sont illustrés à la figure 3. Les signaux transmis par les 28 capteurs dynamométriques: résistance totale, vitesse et position de la maquette, ont été stockés sur disquettes après numérisation. Les signaux de seulement 25 de ces capteurs et la vitesse ont été enregistrés simultanément sur bande magnétique. Le logiciel d'acquisition a été préalablement modifié pour tenir compte du nombre accru de capteurs.

Toutes les mesures transmises par les capteurs ont été converties en valeurs correspondantes de charge des glaces. Le point d'application des charges a pu être déterminé par une technique d'analyse itérative, à l'aide d'un programme d'interpolation des tracés de coque fondé sur la construction de fonctions splines cubiques décrivant les tracés à diverses lignes d'eau. Ces tracés, tirés du plan de formes, avaient la précision de celui-ci. Ce mode de représentation a permis de définir n'importe quel point à la surface de la coque en coordonnées géométriques et en valeurs angulaires. Il y a lieu de faire observer que, malgré son utilité, ce mode de représentation ne correspond qu'au plan de formes. Plus le nombre de tracés est élevé, plus la précision sera grande, notamment là où la coque présente une courbe irrégulière plus ou moins au droit de l'épaule, où les mesures angulaires perdent de leur précision. Il ne faut pas oublier non plus que la forme de la maquette peut dévier du plan de formes et que les écarts qui sont minimes lorsque la maquette est réalisée sur une machine à commande numérique peuvent être importants lorsqu'elle est modelée à la main.

L'analyse de données s'est faite à l'aide d'algorithmes permettant de définir les efforts s'exerçant durant les essais en bassin des glaces: point d'application, amplitude et orientation, et qui ont été ensuite décomposés en leurs trois composantes: une composante normale à la coque, une composante de frottement et l'angle formé par celle-ci et le plan tangent au point d'application.

Un programme d'étalonnage exhaustif et multiniveaux a été entrepris aux fins de vérifier que le système est bel et bien étalonné, de s'assurer qu'il ne comporte pas d'erreurs et d'éliminer, ou du moins minimiser, tout en les chiffrant, les facteurs d'incertitude à chaque niveau dans l'instrumentation de la maquette. En voici les grandes lignes:

- Etalonnage des capteurs: déterminer les facteurs de conversion, la linéarité et l'hystérésis.
- Etalonnage interne des segments: évaluer l'interaction entre les capteurs et le segment correspondant.
- Etalonnage externe des segments: évaluer la réponse de chaque segment aux composantes normales et de frottement, tant dans l'eau que hors de l'eau.
- Etalonnage de la maquette flottante: évaluer la réponse de chaque segment aux mouvements (roulis, tangage, pilonnement) ainsi que l'influence des efforts hydrodynamiques en eau libre.

La méthode utilisée a été celle du chargement progressif à l'aide de masses inertes. La plupart des capteurs dynamométriques, fabriqués en 1983, ont dû être réétalonnés. Les facteurs utilisés ont varié quelque peu par rapport aux précédents, étant à la hausse par un facteur moyen de 2,3 p. 100. Une très bonne linéarité a été obtenue et l'erreur d'hystérésis a été très faible. Une tentative a été faite pour mesurer la sensibilité croisée des capteurs dynamométriques au frottement de glissement. Il a été constaté que les variations dynamométriques maximales résultant du glissement sont indépendantes de la charge et que leur valeur moyenne est inférieure à 0,5 p. 100 de la charge nominale.

L'étalonnage interne a permis d'approfondir la réponse des capteurs dynamométriques de compression à toute valeur ajoutée à la précontrainte d'un des anneaux encastrés dans chacun des segments. Etant donné que la somme totale des efforts doit être égale à zéro, toute surcharge sur un appui doit être compensée aux autres appuis, de manière à maintenir l'équilibre. Les variations des efforts ont été obtenues en augmentant ou diminuant la précontrainte dans chacun des anneaux.

L'étalonnage externe a été réalisé grâce à un montage construit exprès, illustré schématiquement à la figure 4 et photographiquement à la figure 5. Grâce à ce montage, il a été possible de mesurer les composantes des efforts externes appliqués en un point et à un angle prédéterminés. La même technique a été utilisée pour l'étalonnage des trois segments, dans l'eau et hors de l'eau. L'effort appliqué a été mesuré, ainsi que la réponse des capteurs dynamométriques correspondants. Un total de 36 points d'étalonnage ont été choisis sur les trois segments couvrant toute la partie segmentée de la coque,

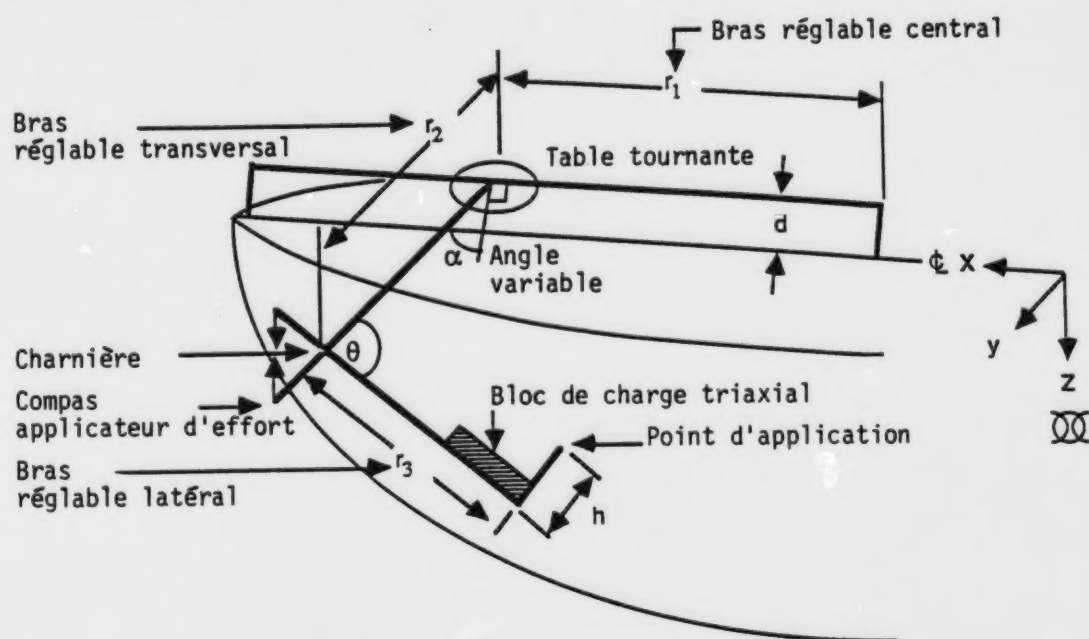


Figure 4 Montage d'étalonnage

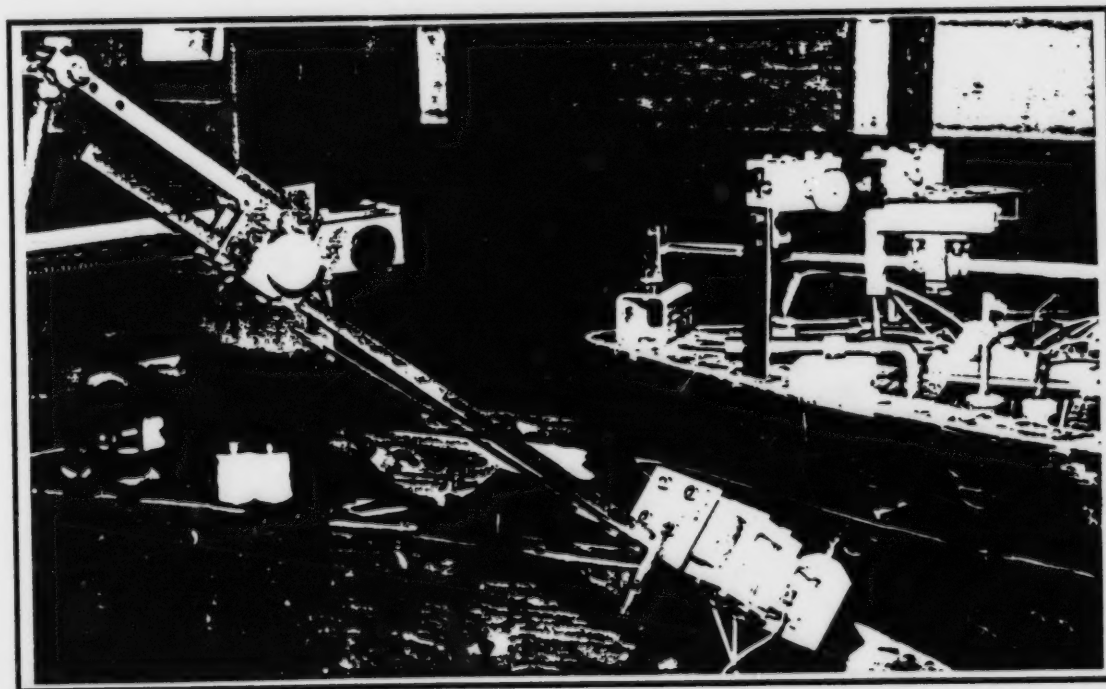


Figure 5 Charge du segment 1 à l'aide du montage

entre les positions $7\frac{1}{2}$ et $10\frac{1}{2}$ pieds et, horizontalement, entre les lignes d'eau 24 et 16 pieds. Les coordonnées des points d'étalonnage considérés ont été obtenues grâce au programme d'interpolation, ainsi que les valeurs angulaires à ces points. Les paramètres spécifiques du montage ont aussi été calculés. Au droit de chaque point d'étalonnage, la charge a été appliquée progressivement en plusieurs étapes (de deux à six) et les signaux dynamométriques correspondants ont été enregistrés et convertis en valeurs de charge à l'aide des algorithmes d'analyse. Celles-ci ont été ensuite comparées aux charges elles-mêmes. La figure 6 montre un feuillet d'étalonnage type. Les erreurs de linéarité ont été obtenues par des essais particuliers au cours desquels les charges ont été progressivement ajoutées et ôtées sur les trois segments.

Les essais d'étalonnage interne et externe ont donné les résultats suivants:

- a) Segment 1: comportement assez stable sauf dans l'axe vertical où il tend à surestimer les efforts. Correction faite, la composante normale a pu être évaluée en moyenne à 3 p. 100 près. La réponse globale a été bonne.
- b) Segment 2: la réponse est bonne, mais une réaction complexe a été constatée entre les capteurs dynamométriques, le fait d'en enlever un produisant un effet considérable sur les résultats. Les erreurs accidentelles ont été un peu plus élevées que prévu. Ainsi, des écarts types de 19 et de 15 p. 100 ont été observés dans les axes longitudinal et vertical, respectivement. A remarquer que les erreurs accidentelles selon l'axe transversal sont moindres, l'écart type n'étant que de 1 N.
- c) Segment 3: ce segment au droit de l'épaule s'est généralement bien comporté. Cependant, à cause des faibles angles au plan d'eau et de dévers, les efforts dominants ont été transversaux, comparativement aux efforts longitudinaux et verticaux généralement très faibles. De même les erreurs relatives par rapport à ces axes ont été élevées, à cause surtout de la faible amplitude des forces composantes et du faible coefficient de frottement à la surface de la coque. Le bilan général a été bon.

Au cours des expérimentations, il est apparu que le montage lui-même pouvait être une source d'erreur; ayant été construit rapidement et de manière peu élaborée, il souffrait de certaines imprécisions aux articulations et d'une certaine élasticité due à ses dimensions. Des essais particuliers ont donc été décidés pour repérer les erreurs attribuables au seul montage.

Segment n° 3

Position 46

Nov 17

Position étalonnage 46

Capteur	Lecture (N)
R-31	2,65
R-32	0,39
H-31	18,12
H-32	-0,35
H-33	1,18
V-31	-5,08
V-32	22,49
V-33	0,70
V-34	-1,06
V-35	1,42
V-36	0,59
T'V	9,82
T'L	-2,74
NOR	26,28

Effort selon l'axe		Appliqué	Mesuré	Écart (%)	Erreur (N)
X		3,56	3,04	-15,0	-0,5
Y		19,39	18,95	- 2,0	-0,4
Z		20,15	19,07	- 5,0	-1,1

Móments par rapport au navire à la ligne de flottaison de 24,75 pi

C1 = -6,70 X Plan
 C2 = 13,41 Y Plan
 C3 = -12,22 Z Plan

Position		Appliqué	Mesuré	Erreur
:X=		1,613	1,607	-0,006 m
Z=		0,027	0,021	-0,006 m
Angle au plan d'eau		18,0	18,0	-1,0°
Angle de dévers		27,0	26,0	-1,0°
Effort total		28,188	27,049	-4,0%
Composante normale		26,279	25,187	-4,2%
Coefficient de frottement		0,388	0,392	
Force de frottement		10,198	9,862	-3,3%
Angle de frottement par rapport à l'horizontale		106,0	107,0	1,0°

Figure 6 Feuille d'étalonnage

Les résultats ont montré que, en effet, dans une certaine mesure, il était source d'erreur et même d'écarts dans les erreurs. Toutefois, à moins de pouvoir mesurer l'erreur au lieu même correspondant à chaque point d'éta-lonnage, il n'est pas possible de séparer les erreurs dues au montage de celles dues aux segments. Ces dernières étaient causées par le mésalignement des capteurs, les imprécisions d'ordre dimensionnel, les sensibilités croisées, etc.

Néanmoins, prise globalement, la précision reste quand même acceptable. Une analyse approfondie a montré que la plupart des erreurs étaient distribuées autour d'une moyenne constante et que la variance était, elle aussi, constante.

L'erreur combinée (linéarité et hystérésis) des segments est bien dans la limite des erreurs accidentelles constatées durant les opérations d'éta-lonnage, les raisons dans les deux cas étant probablement les mêmes. Sans facteur de correction, les segments peuvent mesurer les forces normales à 10 p. 100 près, ou moins, en moyenne, et les forces de frottement à 25 p. 100 près, toujours en moyenne (remarquer le faible coefficient de frottement et l'ampli-tude du frottement lui-même). Ces forces ont pu être localisées avec une précision de $\pm 0,02$ m longitudinalement et de $\pm 0,005$ à $0,010$ m verticalement pour ce qui est des segments 1 et 2. Quant au segment 3, les précisions correspondantes ont été plus faibles, soit de $\pm 0,03$ et de $0,02$ m, respecti-vement. Quant à l'angle de frottement, la précision a été de ± 15 degrés à l'égard d'un coefficient de $0,20$ ou plus.

L'éta-lonnage de la maquette flottante a été fait en vue d'évaluer la réponse de chaque segment aux mouvements de l'eau (tangage, roulis et pilon-nement) lorsque la maquette est stationnaire et lorsqu'elle est remorquée en eau libre à des vitesses variées. Le pilonnement a été le mouvement qui a le moins influencé les capteurs, les capteurs verticaux ayant été les plus sensibles, tous mouvements confondus, et surtout dans le segment 3. Les sensi-bilités types ont été de l'ordre de 4 et de $0,6$ N/degré pour ce qui est du tangage et du roulis, respectivement, et de $0,2$ N/mm pour ce qui est du pilon-nement. Par contre, durant les essais de traction en eau libre, les réactions ont été presque nulles, tout au plus de l'ordre de newton.

Les essais ont eu lieu dans trois couches de glace ayant l'épaisseur et la résistance suivantes: 20 mm/ 35 kPa, 27 mm/ 25 kPa et 47 mm/ 30 kPa. La vitesse imprimée à la maquette a varié entre $0,10$ et $0,66$ m/s, ce qui corres-pond en vraie grandeur à des vitesses allant de $0,9$ à $5,7$ noeuds. Pour les essais, la maquette fixée au chariot d'entraînement n'a subi aucun mouvement de tangage, de pilonnement ou de roulis, ni de lacet, celui-ci ayant été éli-miné par un harnais à l'arrière.

Le point d'application, l'amplitude et l'orientation des efforts ont été déterminés par l'analyse des résultats extensométriques de tous les essais. La figure 7 montre l'évolution des efforts en fonction du temps par rapport au segment 2 lors d'un essai type. Etant donné que le réseau de capteurs ne fonctionne qu'à partir d'efforts d'un certain ordre, la limite inférieure de prise en compte des efforts enregistrés a été établie à 5, 8 et 12 N pour les segments 1, 2 et 3, respectivement. Cette limite inférieure semble être proportionnelle à la masse du segment correspondant. Il faudra donc que, à l'avenir, la masse des segments soit le plus faible possible.

Les essais ont été de quatre types différents, à savoir:

- a) Glace intacte (NS): un premier passage standard de déglacage.
- b) Elargissement du chenal (CW): un deuxième passage pour lequel l'axe longitudinal de la maquette est aligné sur le bord du chenal, du côté bâbord où se trouvent les segments.
- c) Frottement (SS): la maquette avançant à un angle de lacet de 25 degrés frotte contre la glace, au droit du segment 2, entre les positions 9 et 9,5.
- d) Impact (II): des fragments de glace sont poussés manuellement contre un des segments ou sont entraînés manuellement le long de ceux-ci, en différents endroits. Cet essai, qui fournit surtout des résultats qualitatifs, a fait l'objet d'une description peu commentée.

La phase I de cette étude avait mis en évidence deux graves défauts: les pertes de contact segment-capteur et les importantes dérives du zéro lors des essais dans les glaces. Ces défauts ont mené aux modifications apportées aux appuis ainsi qu'au dispositif de précontrainte. Lors de l'évaluation du système dans son état actuel, l'un des tout premiers critères a été la confirmation de la disparition de ces défauts. Les résultats de l'évaluation sont les suivants:

- a) Plus de pertes de contact, grâce à une précontrainte adéquate.
- b) Réduction appréciable des dérives du zéro. Près de 60 p. 100 des capteurs ont donné d'excellents résultats de ce côté, ne montrant qu'une dérive négligeable (moins de 0,5 N par rapport à une capacité de 100 N) comparativement à 4 p. 100 durant la phase I. Les capteurs dont les performances ont été médiocres ne représentent plus que 4 p. 100, comparativement à 20 p. 100 antérieurement. La dérive ne peut être complètement éliminée étant donné la possibilité que les segments bougent lorsqu'ils sont chargés, ne serait-ce que très légèrement. Il est à noter que même si une dérive de 4 N par rapport à une capacité de 100 N est considérée comme élevée, elle ne correspond toutefois qu'à un mouvement de $\pm 0,5$ micron, ce qui est quand même négligeable.

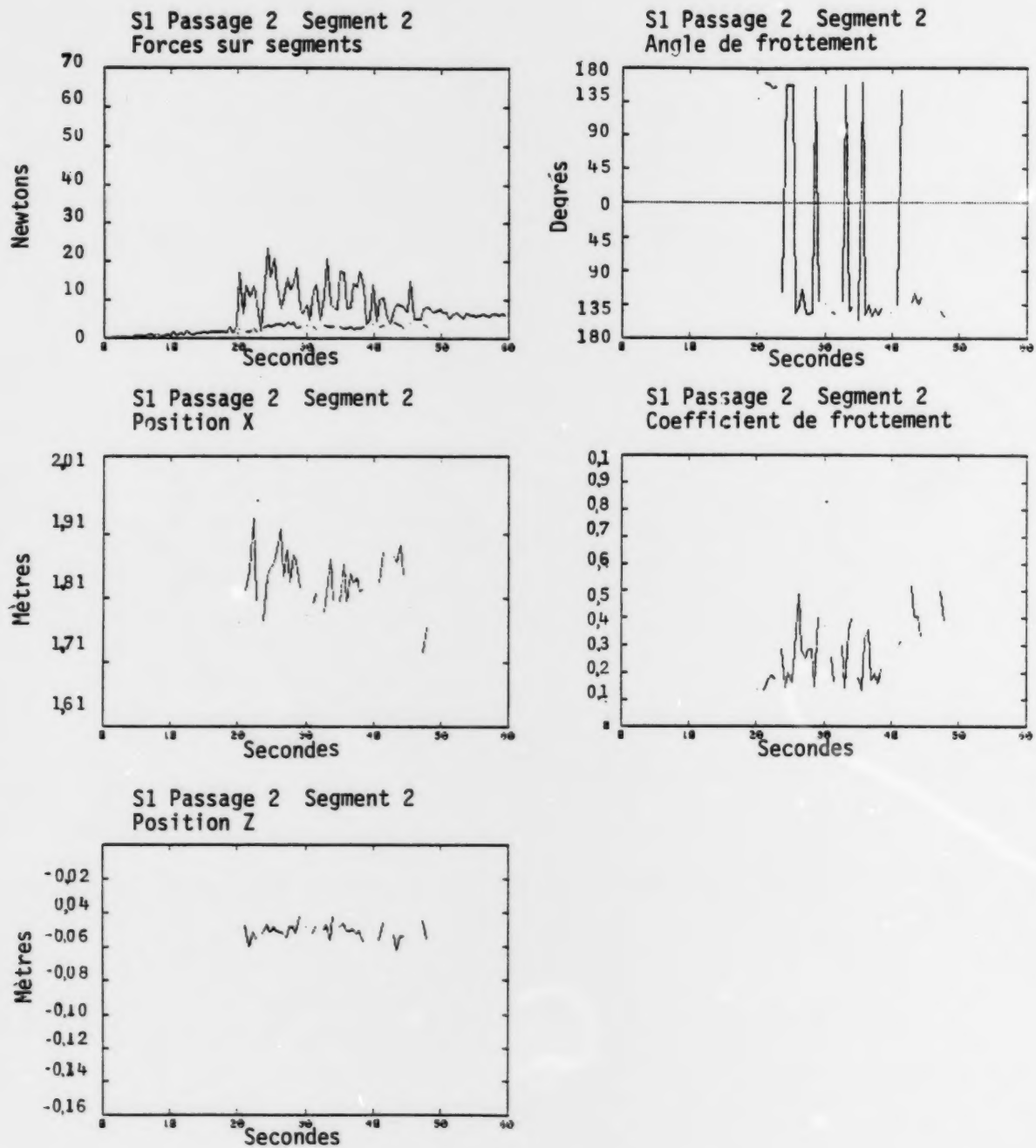


Figure 7 Analyse des efforts - Variations types
($h = 27 \text{ mm}$, $V = 0,45 \text{ m/s}$, $\sigma_f = 25 \text{ kPa}$)

Donc, la première observation à faire est que les modifications apportées ont réussi à éliminer ou du moins à minimiser les défauts majeurs constatés durant la phase I.

L'analyse des résultats des essais dans une glace uniforme et d'élargissement du chenal ouvert dans des conditions comparables montre que les composantes normales mesurées croissent avec les vitesses, l'épaisseur de la glace et aussi selon le segment considéré. La figure 8 montre les variations de la composante normale rapportée à une longueur unitaire du segment correspondant (pour normaliser l'influence de cette longueur) en fonction de la vitesse et de l'épaisseur.

Afin d'examiner l'effet de certains paramètres de la coque sur la composante normale et la corrélation entre celle-ci et certaines variables, trois essais ont été sélectionnés aux fins d'analyse. Ils ont été effectués dans une glace mince (27 mm/25 kPa) et épaisse (48 mm/30 kPa) et à la vitesse de 0,14, 0,22 et 0,3 m/s. L'évolution de la composante normale a été examinée et seules les valeurs maximales ont été retenues puis étudiées afin de mettre en évidence d'éventuelles corrélations.

La figure 9 montre les variations de la composante normale en fonction de la position le long de la coque; ainsi, les valeurs les plus faibles correspondent au segment 1, à l'avant, et cette composante augmente progressivement à mesure que l'on se déplace vers l'arrière. En fait, la charge est multipliée environ par cinq, de l'avant à l'arrière. La même tendance et aussi presque le même rythme de croissance des efforts ont été constatés dans la glace mince, mais à un ordre de grandeur plus faible. On observe aussi des limites supérieures et inférieures bien délimitées dans les données, ce qui confirme cette tendance et montre la dispersion généralement observée dans les résultats sur la charge des glaces.

Quant aux variations verticales de cette même composante, elles ne sont importantes ni en fonction de la position le long de la coque, ni en fonction des charges. Toutefois, dans le cas de la glace épaisse, les efforts agissant sur les segments 1 et 2 l'ont été à une distance d'environ la moitié de l'épaisseur de la glace sous la flottaison, tandis que, pour le segment 3, le point d'application de cette composante se trouvait de 10 à 15 mm plus bas. Ceci est indicatif d'un changement dans le mécanisme de rupture se produisant au droit du segment 3. Dans la glace mince, ce changement apparaît plus tôt, soit au droit des segments 2 et 3. A remarquer aussi, la faible dispersion des données, comme le montre la figure 10.

Etant donné que les angles de carène varient le long de la ligne d'eau, les variations de la composante normale en fonction des angles au plan d'eau et de dévers ont été portées sur trois graphes, correspondants à trois cas différents (figures 11 et 12). On remarque que la force normale croît à mesure que décroissent les angles correspondants et aussi que, aux mêmes valeurs angulaires, il y a chevauchement des données pour les segments 1 et 2.

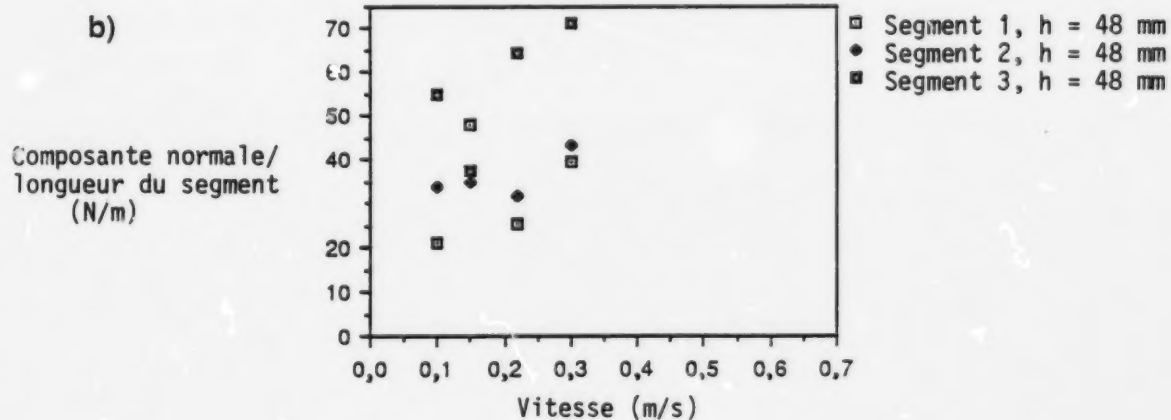
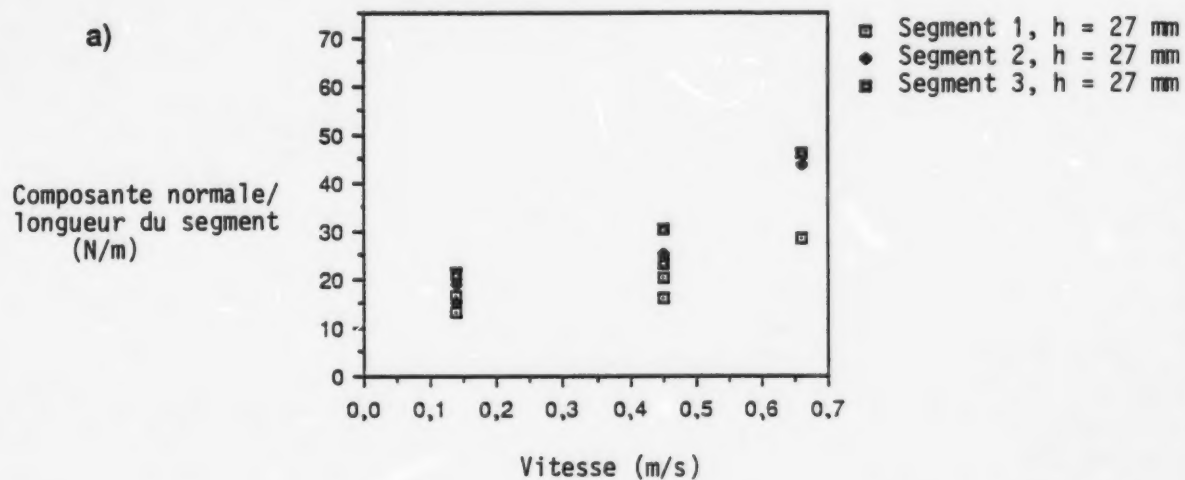


Figure 8
Composante normale par unité de longueur
a) $h = 27$ mm; b) $h = 48$ mm

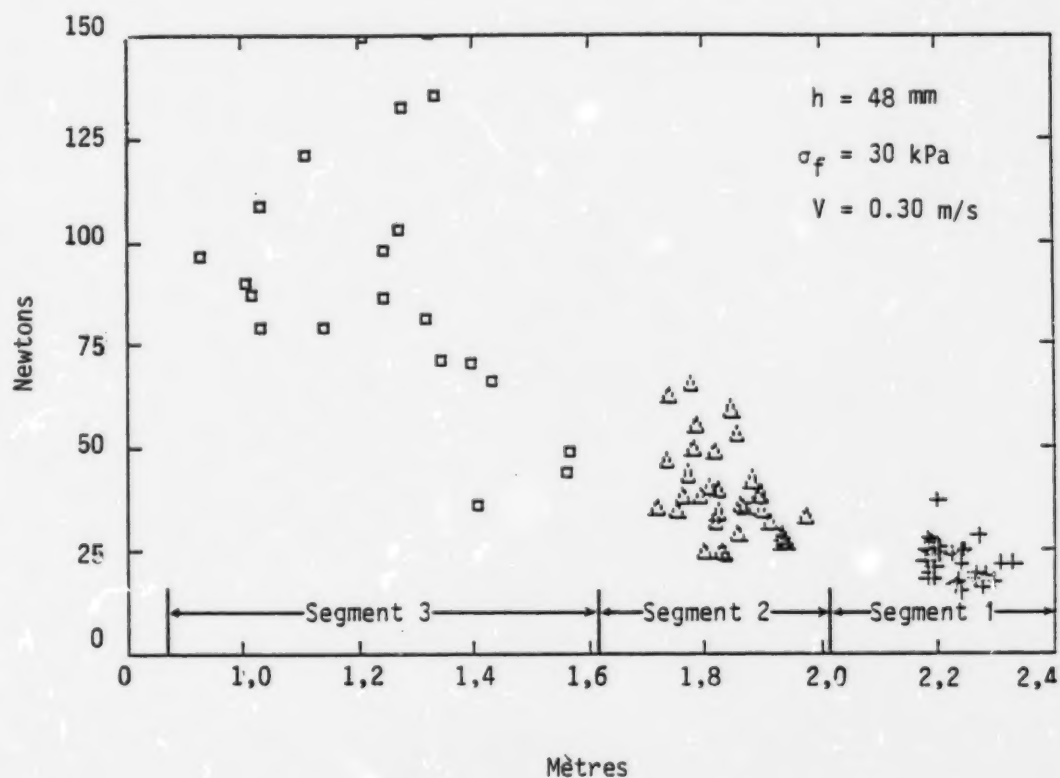


Figure 9 Position des efforts maximums normaux le long de la coque durant l'essai S32

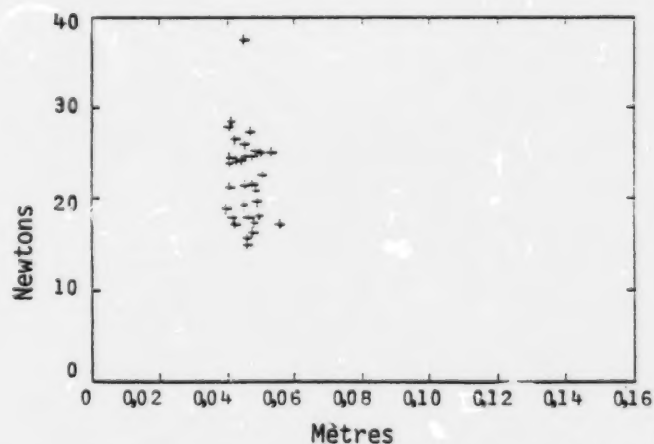


Figure 10 Position des efforts maximums normaux selon la verticale sur le segment 1 durant l'essai S32 ($h = 48$ mm; $V = 0,30$ m/s; $\sigma_f = 30$ kPa)

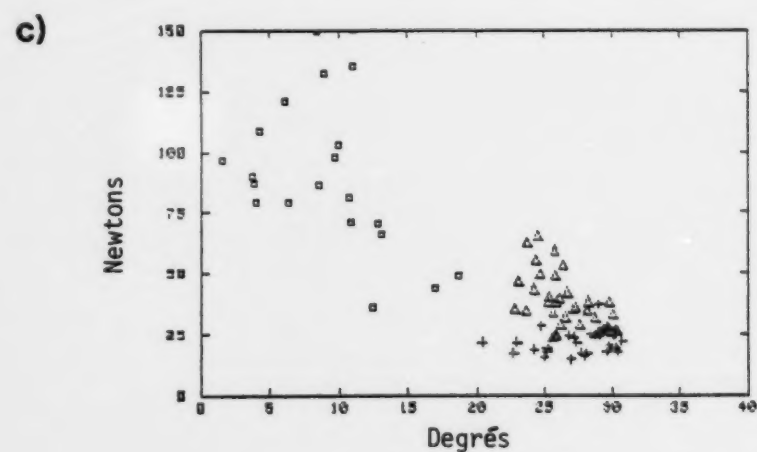
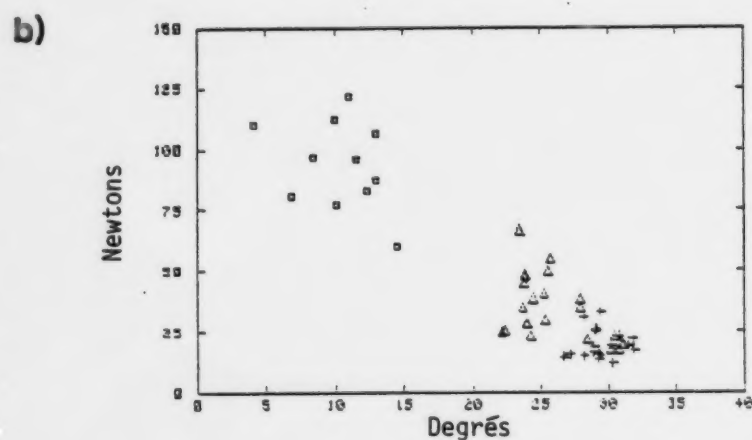
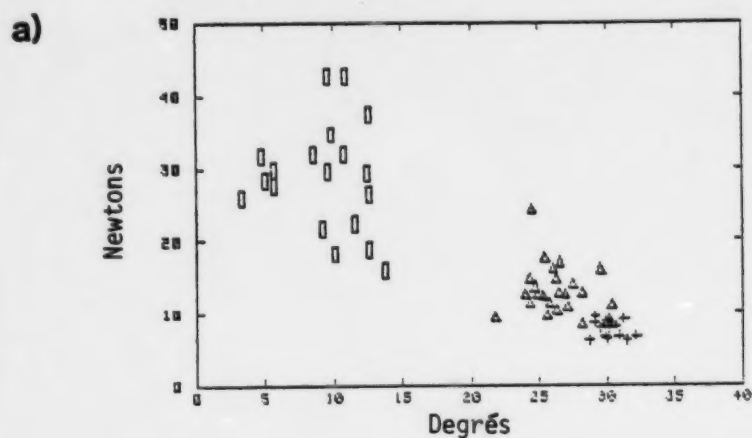
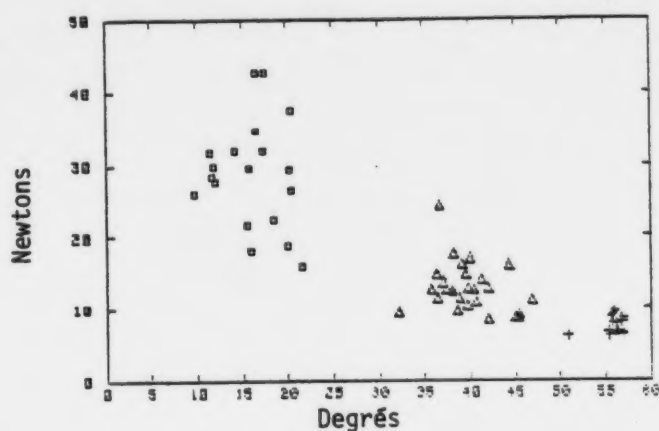


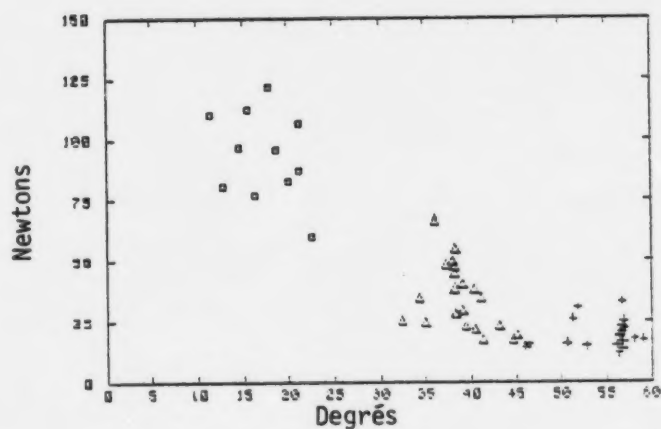
Figure 11 Angles au plan d'eau aux points d'application des efforts maximums normaux durant les essais a) CW5, b) CW9, c) S32

a)



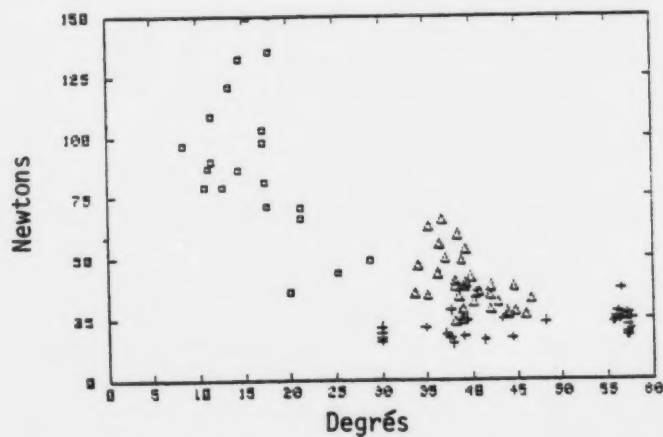
$h = 27\text{mm}$
 $\sigma_f = 25\text{kPa}$
 $V = 0,14\text{m/s}$

b)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0,22\text{m/s}$

c)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0,30\text{m/s}$

Figure 12 Angles de dévers aux points d'application des efforts maximums normaux durant les essais a) CW5, b) CW9, c) S32

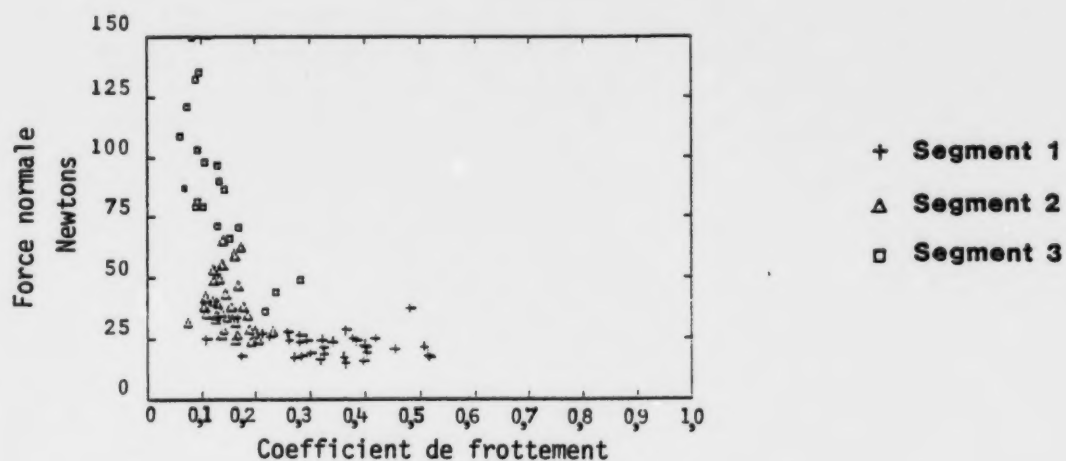


Figure 13 Coefficient de frottement correspondant aux efforts maximums normaux durant les essais S32
($h = 48 \text{ mm}$, $\sigma_f = 30 \text{ kPa}$; $V = 0,30 \text{ m/s}$)

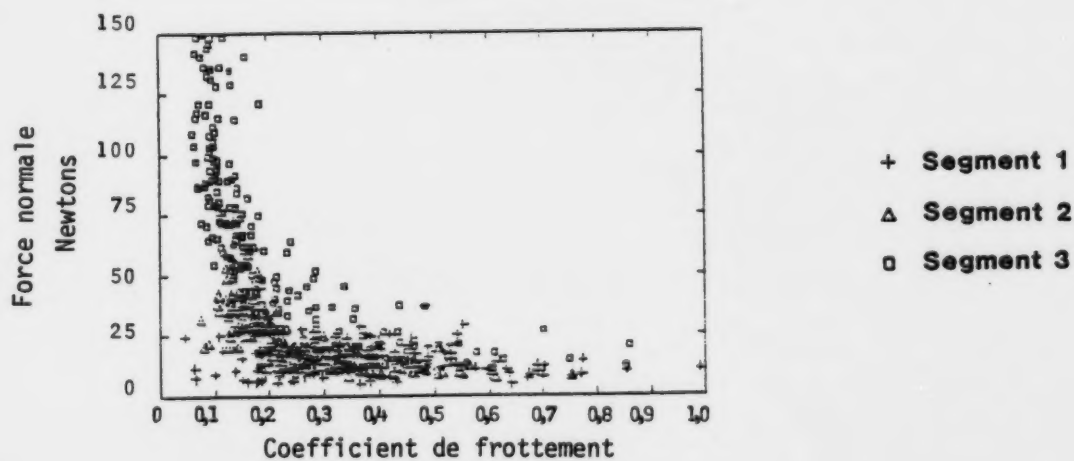


Figure 14 Coefficient de frottement correspondant aux efforts normaux hors échantillonnage durant l'essai S32
($h = 48 \text{ mm}$; $\sigma_f = 30 \text{ kPa}$; $V = 0,30 \text{ m/s}$)

A remarquer aussi que la composante normale semble perdre de sa sensibilité au dévers à partir de 30 degrés et que cette sensibilité est multipliée par trois pour les valeurs faibles d'angle de dévers. Quant à la sensibilité par rapport aux angles au plan d'eau, le rapport semble être linéaire.

En ce qui concerne le coefficient de frottement correspondant aux valeurs maximales de la composante normale, il se maintient à des valeurs entre 0,08 et 0,15 pour les segments 2 et 3, beaucoup plus basses en tout cas que la moyenne de 0,10 à 0,25 constatée tout au long. Pour ce qui est du segment 1, ce coefficient varie beaucoup, entre 0,02 et 0,6. La figure 13 montre les variations du coefficient par rapport aux maximums de la composante maximale normale et la figure 14 par rapport à toutes les valeurs de la composante normale sans exception.

Il est à noter la relation inverse entre le coefficient de frottement et la composante normale, ce qui confirme les constatations antérieures sur le phénomène du frottement dû aux glaces. A l'extrémité supérieure de la courbe des efforts normaux, le coefficient de frottement converge vers une moyenne de 0,1, valeur plus ou moins attendue en ce qui concerne la maquette utilisée. Cependant, à mesure que la composante normale décroît, le coefficient de frottement croît, ainsi que la dispersion. A l'extrémité inférieure de cette courbe on reconnaît que la force de frottement sera faible, elle aussi, tandis que les erreurs de mesure seront considérablement plus élevées.

Enfin, on a cherché les corrélations entre les diverses courbes d'évolution et les observations vidéo, en s'efforçant de déterminer les phénomènes physiques qui correspondaient aux forces maximales enregistrées sur chacun des segments. Au droit du segment 1, les valeurs maximales se produisent au début de la rupture de la glace ou tout de suite après. Donc, ce sont des charges clairement associées à la rupture. Au droit du segment 2, les pointes très fines (durée: 0,5 à 0,9 seconde) correspondent à la rupture et au début du retournement. Le glissement et le choc des fragments contre la coque correspondent à des efforts de faible amplitude. Au droit du segment 3, les phénomènes physiques sont sensiblement plus difficiles à caractériser.

Toutes ces expérimentations ont mené aux conclusions suivantes:

1. Le défaut dans le dispositif d'appui des segments a été éliminé grâce à un nouveau dispositif de précontrainte à raideur accrue, qui permet un réglage précis de sorte que les pertes de contact segment-appui ont disparu. Un autre avantage de ce dispositif a été de réduire les mouvements des segments chargés et, de là, les dérives de zéro. Enfin, grâce à un usinage approprié des surfaces d'appui, les erreurs de mesure attribuables aux capteurs ont été ramenées à moins de 1 p. 100.

2. Le montage construit pour assurer l'étalonnage des segments manque de raideur structurale, de sorte qu'il constitue une source possible d'erreurs. Compte tenu de ceci, des facteurs de correction et des marges d'erreur ont pu être déterminés ainsi que les limites inférieure et supérieure des erreurs. L'erreur combinée (linéarité et hystérésis) dans les segments est inférieure à l'erreur globale; elle contribue probablement aux erreurs accidentelles attribuables à chacun des segments. Des étalonnages répétés au même point de chaque segment ont confirmé la fidélité des mesures.
3. Par le procédé de la segmentation, la maquette est devenue un outil de recherche qui permet de calculer les charges dues aux glaces, la composante de frottement de celles-ci, leur position et leur direction. Par un étalonnage soigné de la maquette, il a été déterminé que, dans une limite de confiance de 68 p. 100, la marge d'erreur dans le calcul de la composante normale est inférieure ou égale à ± 13 p. 100 de la valeur totale selon le segment considéré et que, pour ce qui est de l'effort de frottement, cette marge est égale à ± 40 , ± 47 et ± 14 p. 100 pour les segments 1, 2 et 3, respectivement. Même si la marge d'erreur dans les mesures de frottement paraît élevée, l'erreur absolue, elle, est faible vu la faible amplitude des efforts de frottement. Ceux-ci ont pu être localisés sur le segment avec une marge d'erreur de ± 5 p. 100 selon l'axe des x et de ± 7 p. 100 selon l'axe des z. Quant à leur direction, elle a été déterminée avec une marge d'erreur de ± 15 degrés pour les coefficients supérieurs à 0,2.
4. Les résultats des études en bassin des glaces montrent que la résistance exercée par celles-ci sur les trois segments est largement tributaire de leur épaisseur et de la vitesse imprimée à la maquette. Quant au mode de rupture, déterminé par la concentration des efforts maximums, il est grosso modo proportionnel à l'épaisseur de la glace. L'amplitude des efforts maximums évoluait à l'inverse de l'évolution des angles au plan d'eau et de dévers. De même, une tendance a été nettement observée montrant que la composante normale augmente exponentiellement de l'avant vers l'arrière et que le coefficient de frottement évolue exponentiellement et à l'inverse de cette composante. Quant à la direction du frottement, elle est très erratique, mais presque toujours descendante sur les segments 1 et 2 et, légèrement vers l'arrière, mais toujours vers le bas, en ce qui concerne le segment 3.
5. Les essais dans les glaces ont été effectués avec la maquette maintenue restreinte à un seul degré de liberté de mouvement. La correction des mesures pour tenir compte des mouvements de tangage, de roulis et de pilonnement n'a donc pas été nécessaire. Néanmoins, lors d'essais statiques séparés, la sensibilité de la maquette à ces mouvements a été enregistrée, ce qui a débouché sur les facteurs de correction correspondants. Il a été constaté que la maquette était sensible au roulis et au tangage, de sorte que des facteurs de correction deviendront nécessaires si des essais de traction "libre" devaient être effectués.

Plusieurs recommandations peuvent être formulées concernant la technique de segmentation des coques et touchant trois domaines distincts:

1) perfectionnement de la technique actuelle, 2) nouvelles applications de celle-ci visant à approfondir nos connaissances du phénomène et du mécanisme de rupture et 3) prochaine génération de maquettes à coque segmentée. Les voici donc, dans l'ordre cité:

1. Perfectionnement de la technique actuelle

Accroître la précision du programme d'interpolation des tracés de coque, en relevant les coordonnées du segment 1 de la maquette et en les substituant aux tracés mis en mémoire. Affiner l'algorithme de réduction des données pour une vitesse de convergence accrue des calculs. Accroître la raideur du montage d'étalonnage, afin d'éliminer les erreurs attribuables au modèle actuel lors des opérations d'étalonnage.

2. Nouvelles applications de cette technique

- a) Les résultats montrent que les efforts augmentent de l'avant à l'arrière, mais on ne sait pas si, passé l'épaule (qui correspond au segment 3), l'amplitude de ces efforts retombe. Par l'inclusion d'un quatrième segment juste avant le segment 3, il sera possible de mesurer les efforts sur la partie médiane et rectangulaire de la coque et de décrire avec plus de précision la distribution des efforts sur la coque de la maquette.
- b) Procéder à une batterie complète d'essais dans une glace uniforme afin de valider les théories édifiées, sur la résistance des glaces, par Carter et Arctec Canada Limited (RICE). Le programme des essais devra tenir compte de tous les paramètres: épaisseur et résistance à la rupture en flexion de la glace, allure de marche et coefficient de frottement. Plus particulièrement, examiner les variations de la composante normale le long de la coque. Confronter la direction théorique du frottement le long des coupes longitudinales ou des lignes d'eau à la direction calculée à partir des résultats obtenus.
- c) Approfondir l'influence du frottement coque-glaces. D'après les essais, la force de frottement augmente exponentiellement à mesure que diminue la composante normale. Il serait utile de savoir s'il s'agit d'un phénomène naturel se vérifiant dans les faits ou s'il s'agit d'un artéfact de l'essai. Pour ce faire, on pourra, par des moyens classiques, varier le coefficient de frottement lors des essais dans les glaces entre 0,03 et 0,5. Les mesures permettront de repérer les variables dépendantes de l'effort de frottement et expliqueront les divergences dans les résultats du mesurage relatif à la direction de ces efforts.

3. Prochaine génération de maquettes segmentées

- a) Tirer parti de la technique de segmentation, qui permet d'optimiser la forme des coques, en réalisant une maquette type dont les segments seraient non seulement amovibles, mais aussi remplaçables par d'autres de forme différente, et ce, en utilisant le même dispositif d'appui ainsi que la même chaîne de mesure. La première étape consisterait donc à réaliser la maquette de base dotée d'une chaîne de mesure polyvalente qui autoriserait une variation importante de la forme des segments de remplacement, ceci sans modifier la trame de segmentation.
- b) Procéder, par la suite, à des études sur la coque d'un navire sélectionné pour l'intérêt qu'il présente, tel le brise-glace POLAR 8. Ainsi, il sera possible de procéder à une évaluation approfondie des différentes formes de coque à l'étude, dans le but d'en connaître les performances potentielles et, éventuellement, de les optimiser.

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NOMENCLATURE

C_1, C_2, C_3	moments about the x, y and z axis, respectively
d	vertical distance from 24.75' WL to r_2
$\vec{e}$	friction vector
E	modulus of elasticity
F	force
F_a	applied force
F_f	friction force
F_m	measured force
F_n	normal force
F_R, F_H, F_V	force in the longitudinal, horizontal and vertical direction respectively
F_{TOT}	total force
F_x, F_y, F_z	force in the x, y and z directions respectively (equivalent to F_R, F_H, F_V)
F_θ	force in the x-y plane which is normal to the waterline
H_{ij}	horizontal transducer j on segment i
$\vec{i}, \vec{j}, \vec{k}$	unit vectors on axes x, y z
k	spring stiffness
l_c	characteristic length
$\vec{n}$	vector normal to the hull surface
o'	origin of orthogonal coordinates at a point on the hull
NOR, T'_1, T'_V	calibration rig transducers
r_1	length of calibration rig arm which is along the model centerline
r_2	length of calibration rig arm which is normal to the waterline and parallel to the the waterplane
r_2'	distance from the centerline to r_3' at the 24.75' WL

r_3	length of calibration rig arm which is in the plane tangent to calibration point
r_3'	distance from 24.75' WL to calibration point in the plane tangent to the calibration point
R_{ij}	longitudinal transducer j on segment i
v	speed
V_{ij}	vertical transducer j on segment i
WL	waterline
x, y, z	left hand cartesian coordinates with origin at 24.75' WL, centerline and midships. x is the longitudinal direction, y is the horizontal direction and z is the downward vertical direction.
α	alpha - water line angle
α_c	angle between r_1 and r_2 minus 90°
β	beta - flare angle - angle from vertical of the buttock line
β_c	angle of calibration rig arm r_3 from the vertical
γ	correction factor
$\bar{\gamma}$	mean correction factor
ϵ_{RIG}	error of the calibration rig
ϵ_{SEG}	error of the segment
ϵ_{TOT}	total error of the calibration rig and segment
θ	Theta - normal flare angle; angle from the x-y plane of plane tangent to hull
μ	ratio of friction force to normal force
σ_f	flexural strength
σ_γ	standard deviation of the correction factor
ψ	Psi - angle from the x axis of $\vec{e}$
CL	hull centerline
	hull midships

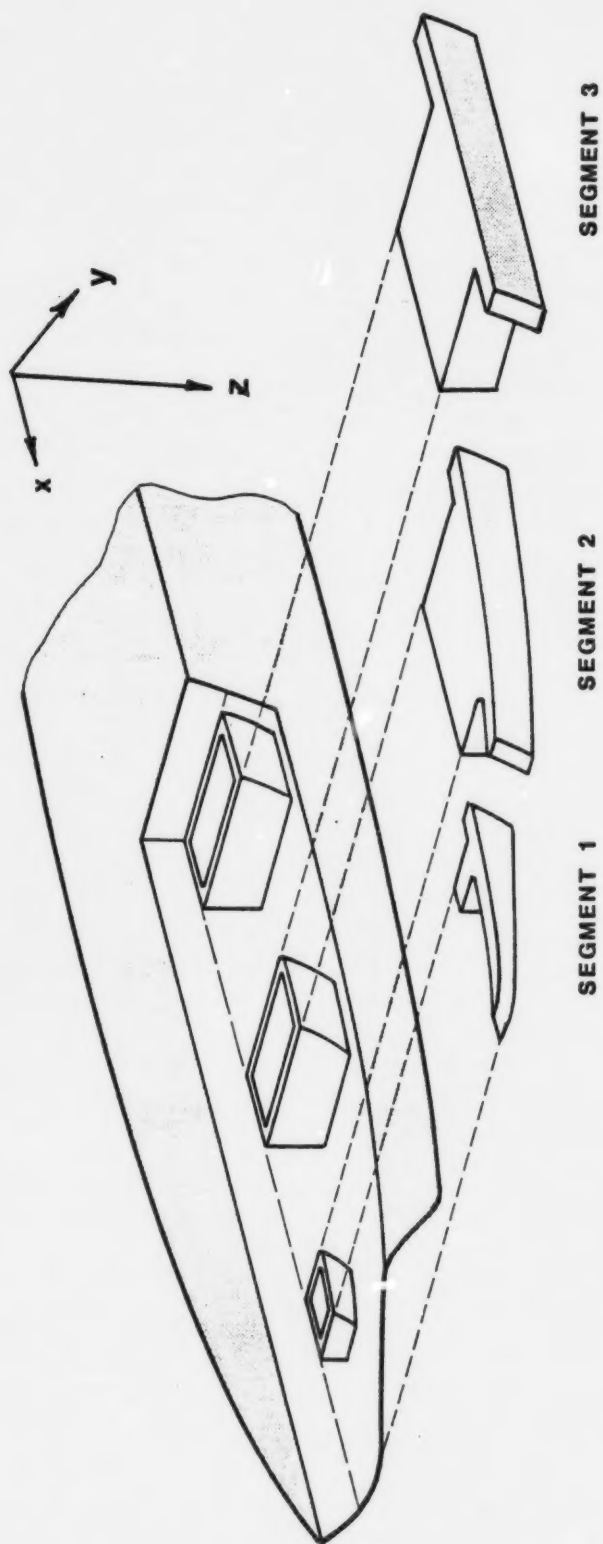


1.0 INTRODUCTION

Ships navigating in ice covered waters must be designed and powered to cope with environmental conditions which vary significantly with location and time of year. One of the major concerns to ship navigation is the resistance of different ice conditions which vary from level to uneven with pressure ridges or large irregular ice features. The prediction of ice resistance to ship motion has been the focus of many research efforts which have been reviewed elsewhere; within the context of the present program of research [1] or during the development of the Arctic Marine Transportation R&D Program for TDC [2] or most recently as part of the Arctic Shipping Technology Program for Transport Canada [3]. The various techniques proposed for prediction of the ice resistance vary from theoretical, to purely empirical, and in the middle semi-empirical techniques combine theory and experiment to produce, on a rational basis, a breed of models which has wider applicability.

The use of segmented models to develop a prediction capability for ice resistance is an innovative approach which has been supported by TDC during the past five years. Earlier efforts [1] have been directed towards the technique development. In [1], the segmentation rationale, methods, and segment support and instrumentation systems have been developed. The CCGS PIERRE RADISSON model hull was used as a basic hull for this study program. The model contains three oblique segments on the port side of the hull. Each segment is independently supported with provision for measurement and tracing of the external ice forces. Figure 1.1 illustrates the overall segmentation plan of the model. Testing has demonstrated that the technique could be used successfully to measure ice forces acting on three independent bow segments. As a result of these preliminary tests, several areas were identified where refinements and improvements were needed. These improvements were carried out during the present phase of the study and are documented in this report. At its present state of development, the technique may be used to examine and understand icebreaking theories and processes.

This report is divided into two volumes. Volume I describes the design modifications performed on the segments; segment support and instrumentation systems; the data acquisition; reduction and analysis systems; the model calibration program and test results, the icebreaking tests: results, analysis and interpretation; and finally the conclusions and recommendations for utilization of the technology which has been developed in this program. Volume II contains the detailed calibration and ice test results.



MAIN DECK OMITTED FOR CLARITY
LEFT HAND COORDINATE SYSTEM WAS USED AS ILLUSTRATED

Figure 1.1 METHOD OF MODEL SEGMENTATION

2.0 DESIGN MODIFICATIONS

2.1 Segment Support System

Each segment is subjected to normal forces and their frictional components. At least six support points are needed on each segment to support these loads: three points in the x, y, and z directions to support the normal load components; and three points in the x-y, x-z, and y-z planes to provide support for the three moment components of load. Also at least five measurements are required to determine the position of the load to its normal component, and its frictional component. The typical segment support system before modifications consisted of seven support points (as shown in Figure 2.1): four in the vertical or z direction, two in the transverse or y direction and one in the longitudinal or x direction. The load is supported at each point using unidirectional load cells; a diaphragm type load cell as shown in Figure 2.2. The load acts on the diaphragm through a ground polished and hardened stainless steel ball, which loosely fits into a polished cup permitting the ball to roll, within certain limits.

Each load cell mates a 1-in. (25 mm) diameter steel load support surface on the segment. The load support surface provides a hard, clean, low friction surface for the ball to act upon.

Part of the modifications included insuring that these load support surfaces are parallel to the principal planes of measurement. This is discussed in more detail in Section 2.4. The stickout clearance between the load cell body and the support surface is critical and a minimum is needed to insure that, given the tolerances in perpendicularity of the load cell to its support surfaces, the body of the load cell will not interfere with the support surface.

Because the load cells only support and do not physically hold the segment there must always be a compressive load on the cells to keep them in contact with the segment. Since the segments are neutrally buoyant an initial preload is necessary to insure that all the vertical load cells are in contact with the segment. Also negative reactions on certain load cells from the ice resistance forces necessitate the application of a sufficient preload to insure that the load cells are always contacting the segment during testing. In this case the preload must be greater than the maximum anticipated negative load at the load cell in question.

These preload requirements mean a pretensioning system must be in place to hold the segment against the load cells. Originally this consisted of two wires, one in the vertical direction and one in the horizontal plane. Tension on the wires kept the segment in contact with the model. The wires were flexible enough so that they carried about 1% or less of the reactive force and therefore their contribution to the overall support system was ignored. However this system was too flexible and contact was not always maintained at the load cells. To remedy this problem it was decided to replace the compliant pretensioning system with a stiffer arrangement.

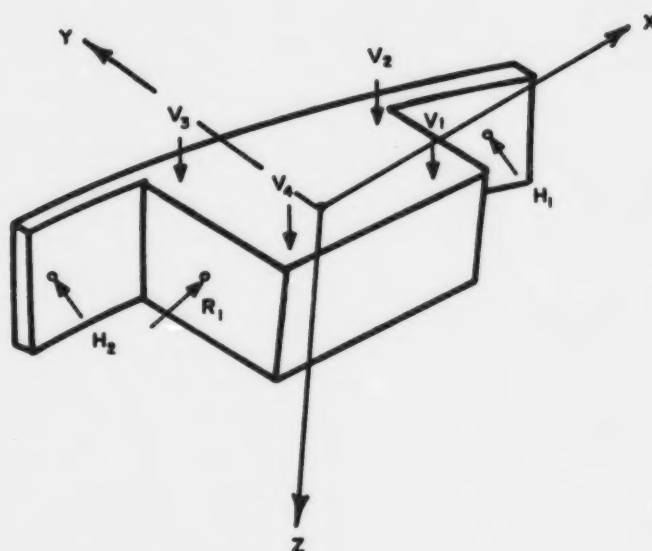
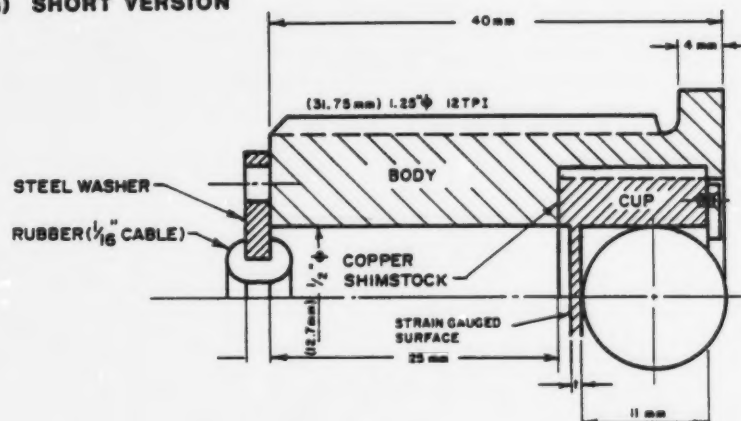


Figure 2.1
TYPICAL SEGMENT SUPPORT SYSTEM BEFORE MODIFICATION

(Subscripts indicate transducer number).

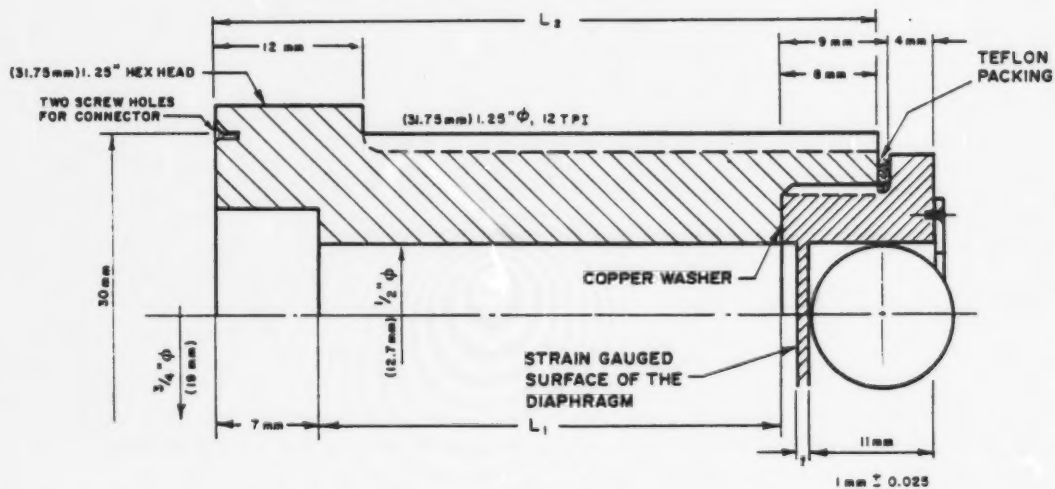
a) SHORT VERSION



b) STANDARD and LONG VERSIONS

STANDARD : $L_1 = 45\text{mm}$, $L_2 = 60\text{mm}$

LONG : $L_1 = 80\text{mm}$, $L_2 = 95\text{mm}$



DIAPHRAGM THICKNESS

$t = 1.00 \pm 0.025\text{mm}$ for 100N RATED CELLS

$t = 0.70 \pm 0.020\text{mm}$ for 50N RATED CELLS

Dimensions given in inches are for the convenience of the manufacturer.

Figure 2.2 ASSEMBLY DRAWING FOR LOAD CELLS

The stiffness would be established so that continuous contact would be maintained during model testing in ice. However, a stiffer system will necessitate the measurement of the pretension and its inclusion in the ice load calculation. Specially designed tension links were used for this purpose, the design of which is described in the following subsection.

2.1.2 Tension Link Design

The objective of the design was to ensure that the new tension links had a stiffness that was of the same order of magnitude as that of the load cells but not greater. Tension links with a stiffness greater than the load cells would carry the largest portion of the load. This can be explained by viewing the segment as a rigid body supported by springs which have stiffnesses equal to the transducer stiffnesses. Transducers are in effect springs which measure force by their displacement. Figure 2.3 illustrates a surface supported by three springs, with the middle spring having a stiffness of k_a and each of the outer two having a stiffness of k_b , and is loaded by a Force F which moves the surface a distance d . The ratio of the reaction at the middle spring, F_a , to the reaction at one of the other springs, F_b , is then k_a/k_b . If k_a is stiffer than k_b , F_a will be proportionally larger than F_b . In the segment support system the middle spring is equivalent to the tension link and therefore the force which it measures is dependent on its stiffness and the stiffness of the surrounding load cells.

As stated earlier, five accurate measurements, with at least one in each principal direction are required. If the tension links are so stiff that they carry the largest portion of the load then the response will be that of three strong signals from the tension links and six or seven weaker ones from the load cells. This would reduce the accuracy of the overall segment since the weak signals would be close to the resolution of the load cells. A better design is for the three tension links to be less stiff than the weakest load cell so that at least five accurate measurements are made of the load cells and three lesser, but not negligible measurements are recorded at the tension links. Each segment has at least two 100 N loads with the remainder being 50 N load cells. Since the 100 N load cells have a stiffness of 18 MN/m and the 50 N load cells have a stiffness of 6.8 MN/m the tension links should not have a stiffness greater than 7 or 8 MN/m.

Since the tension links are to be stiff they will be carrying part of the load. Therefore they must be instrumented so that this load can be measured. They can carry moments if the tension links can be instrumented so that the moments as well as the loads can be measured. To minimize instrumentation and to eliminate changes to the segment data reduction algorithm it was decided to design tension links which could only carry tensile loads.

A ring type transducer was chosen for the tension links since a ring would be able to withstand the maximum loads, stiff enough to approach the stiffness of the load cell, yet sensitive enough to measure loads as low as 1N and sturdy enough to withstand handling during installation, testing, and storage. The maximum loads were determined by examining the maximum allowable preload on each load cell and the weight of each segment. The rings were constructed from 416 stainless steel which has an elastic modulus of 207 GPa and a yield strength of 276 MPa. Three different sizes were made with stiffnesses ranging from 4.3MN/m to 9.3MN/m. Dimensions, ratings, and stiffnesses are given in Table 2.1. On each side of the ring a pair of brass couplings are attached as shown in Figure 2.4. The couplings are at right angles to each other so that they form a small universal joint. The universal joint does not allow any moments to be transferred from the segment to the ring. Four strain gauges were applied to the ring as shown to form a temperature compensated 4 arm bridge.

The entire tension link is fitted inside an aluminum insert and one end of the tension link is fixed to the bottom of the insert as shown in Figure 2.4. Inserts can either be mounted inside the segment with the free end of the tension link passed through a bulkhead and attached to its other side or mounted on the bulkhead with the free end of the tension link attached to the segment. Preloading is applied by tightening the 4-40 nut at the end of each tension link. The overall stiffness of the tension links taking into consideration the end plates and the brass couplings ranges between 2 to 4 MN/m depending on the ring size and the end plates.

2.1.2 Location of Tension Links

Now with a transducer capable of applying and measuring preloads it was necessary to determine the optimum position of the load cells, the number needed per segment, and the preloads that could be applied on the load cells from these positions.

In order to reduce the difficulty in applying the preloads, it was decided to use three tension links on segments 2 and 3 - one for each direction. The tension links were placed in locations which reduced the interactions from load cells acting in perpendicular directions to each tension link. It was decided to place the vertical tension links at the center of buoyancy, to place the transverse tension link midway between the two transverse load cells at the same vertical level, and the longitudinal tension link at the same z coordinate as the longitudinal load cell and as close to it as is practically possible. Thus pretension in the x direction will have a negligible affect on the vertical load cells and pretension in the y direction should have a negligible effect on the longitudinal and vertical transducers. The support system for a typical segment with tension links included is shown in Figure 2.5. The transducers have been labelled R, H or V depending on whether they are in the longitudinal, horizontal or vertical directions, respectively.

Table 2.1
LOAD RING PARTICULARS

Load Ring Rating (N)	140	200	250
Outside Diameter (mm)	30.0	30.0	30.0
Thickness (mm)	2.0	2.15	2.3
Width (mm)	15.0	18.5	19.0
Stiffness (MN/m)	4.3	6.6	9.3

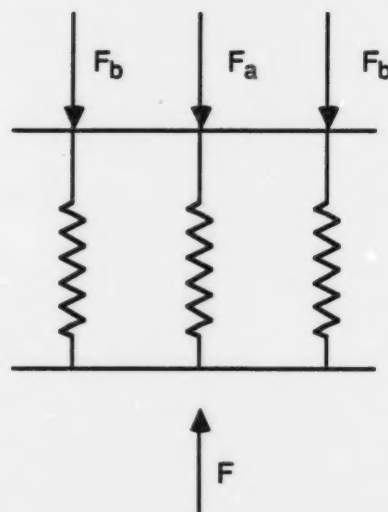


Figure 2.3
SPRING REACTIONS AT A SURFACE LOADED BY FORCE F

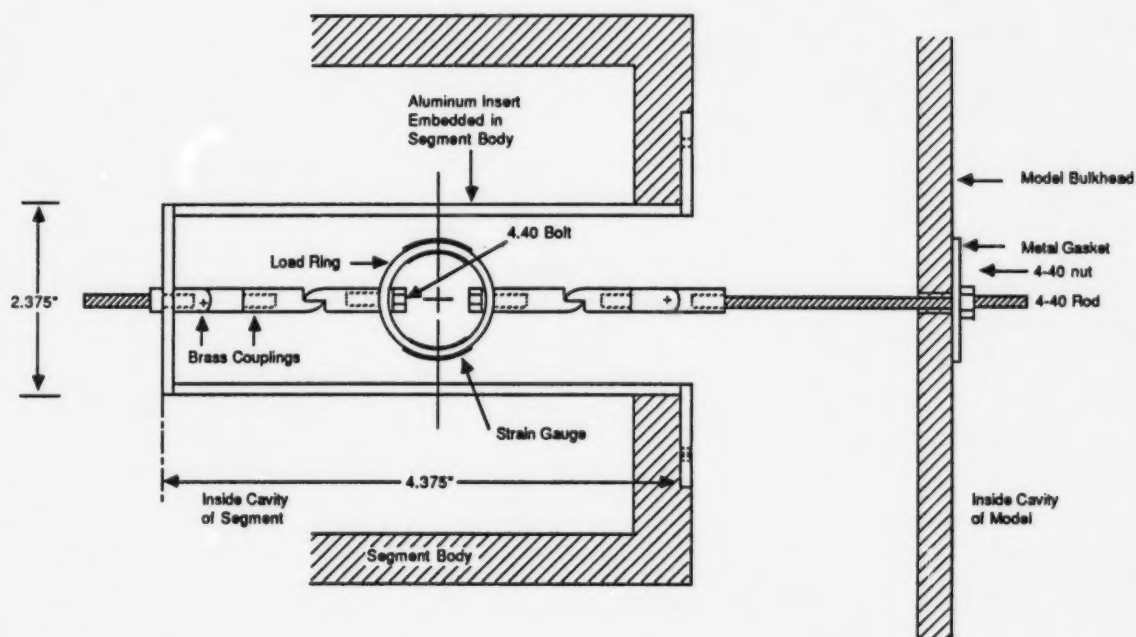


Figure 2.4 TENSION LINK and INSERT

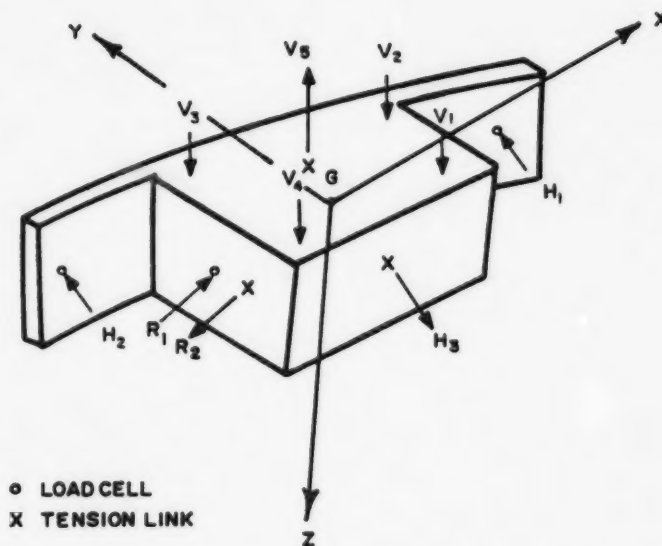


Figure 2.5 TYPICAL SUPPORT SYSTEM WITH TENSION LINKS

A finite element model was constructed for each segment to determine optimum tension link location and minimum and maximum preloads at each transducer.

The models consisted of a rigid body with springs at the transducer locations with the spring stiffnesses equaling the transducer stiffnesses. Three load cases were used on each model. The design load was a 75N normal load, the maximum expected dynamic ice load. One load was applied at each extreme end of the segment and the third at the center. All three loads were applied on the 23' WL ($z = .027$ m) or the 22' WL ($z = 0.42$ m) since the ice loads act principally on these waterlines.

The reactions of the segments to the three load cases are given in Tables 2.2, 2.3 and 2.4 for segment 1, 2 and 3 respectively. From Tables 2.2 - 2.4 the minimum and maximum allowable preloads on each transducer were calculated from the maximum negative reaction expected, the maximum positive reaction expected and the transducer rating. The minimum and maximum preloads are given in Table 2.5. The minimum preload must be equal to the maximum negative reaction. If a negative reaction is not expected then a minimum preload of 5N should be applied to insure initial contact.

The maximum preload plus the maximum positive reaction cannot exceed the transducer rating. If this happens there will be a possibility of damage to the transducer. It should also be noted that the vertical tension links will also have to carry the segment weight in air.

It was observed that in some cases the maximum and minimum preloads on segment 1 may differ by as little as 5N. The segment 1 tension links then must be quite accurately placed so that they can deliver the correct preload to each transducer. To determine the optimum position more finite element analysis was performed in which loads were applied at the tension link locations. The locations were then adjusted until the best locations and angles of the tension links were determined. To begin it was known that the x-z tension link should be at the same y coordinate as R_{11} and as well near the same z coordinate. The y-z tension link should act somewhere near the line connecting H_{11} and H_{12} and should be near the middle of this line. The coordinates optimized then were the x coordinate of the x-z link and the y coordinate of the y-z link.

Also the constraints of mounting the tension links dictated that each had to be angled between 45° and 70°. The results of this finite element analysis are given in Table 2.6 and it can be seen that the correct preloads can be applied with the tension links of the locations and angles indicated.

TABLE 2.2

REACTIONS OF SEGMENT 1 DETERMINED BY FINITE ELEMENT MODEL
FOR A 75N APPLIED NORMAL LOAD

COORDINATES OF LOAD POINT	TYPE C = COMPRESSION T = TENSION LINK	SEGMENT AFT	STATION #10	SEGMENT FORE
x m		2.04	2.198	2.300
y m		.155	.061	.024
z m		.042	.042	.0267
<u>Applied Load</u>				
F _N		26.5	19.9	20.3
F _x ^N		44.4	39.8	45.5
F _y ^N		54.3	60.4	56.0
F _z ^N				
<u>Load Cell Reactions (without Preloads)</u>				
R ₁₁ N	C	26.5	19.9	20.3
H ₁₁ N	C	-23.0	33.7	72.0
H ₁₂ N	C	67.4	6.1	-26.5
V ₁₁ N	C	7.7	33.6	61.9
V ₁₂ N	C	78.8	13.2	-15.4
V ₁₃ N	C	-32.1	13.6	9.5

TABLE 2.3

REACTIONS OF SEGMENT 2 DETERMINED BY FINITE ELEMENT MODEL
FOR A 75N NORMAL FORCE

COORDINATES OF LOAD POINT	TYPE C = COMPRESSION T = TENSION LINK	SEGMENT AFT	STATION #10	SEGMENT FORE
x' m		1.621	1.76	2.02
y' m		.366	0.310	0.183
z' m		.027	0.027	0.027
<u>Applied Load</u>				
F N		21.4	25.1	23.2
F ^x N		60.6	59.2	45.5
F ^y N		38.6	38.5	54.8
F _z N				
<u>Transducer Reactions (without Preloads)</u>				
R ₂₁ N	C	17.8	20.4	18.0
R ₂₂ N	T	3.4	5.0	6.0
H ₂₁ N	C	-22.0	2.2	42.0
H ₂₂ N	C	81.0	53.8	1.8
H ₂₃ N	T	3.2	3.0	2.4
V ₂₁ N	C	-12.2	-9.7	-3.5
V ₂₂ N	C	10.8	27.0	68.4
V ₂₃ N	C	50.4	33.7	-2.8
V ₂₄ N	C	-11.6	-13.2	-13.4
V ₂₅ N	T	0.3	0.6	0.7

TABLE 2.4

REACTIONS OF SEGMENT 3 DETERMINED BY FINITE ELEMENT MODEL
FOR A 75N NORMAL FORCE

COORDINATES OF LOAD POINT	TYPE C = COMPRESSION T = TENSION LINK	SEGMENT AFT	STATION #10	SEGMENT FORE
x m		.910	1.319	1.613
y m		.476	.436	.362
z m		.042	.042	.042
<u>Applied Load</u>				
Fx N		1.7	12.4	21.9
Fy N		73.6	71.3	63.1
Fz N		14.0	19.6	34.1
<u>TRANSDUCER REACTIONS (without Preloads)</u>				
R ₃₁ N	C	2.0	9.5	16.4
R ₃₂ N	T	-0.3	2.9	5.5
H ₃₁ N	C	-3.4	37.4	60.4
H ₃₂ N	C	73.1	30.2	-0.7
H ₃₃ N	T	3.9	3.8	3.3
V ₃₁ N	C	-8.2	-4.8	3.2
V ₃₂ N	C	5.7	15.0	31.1
V ₃₃ N	C	16.4	12.0	4.6
V ₃₄ N	C	-4.2	-8.2	-13.1
V ₃₅ N	T	1.44	3.2	6.4
V ₃₆ N	T	2.9	2.4	1.9

TABLE 2.5
SUPPORT SYSTEM PRELOADS

LOAD CELL DESIGNATION	TYPE C = COMPRESSION T = TENSION LINK	ANTICIPATED LOAD RANGE N (from F.E. model)	SPECIFIED RATING N	PRELOAD MIN N MAX	
SEGMENT 1:					
R ₁₁	C	0 - 27	100	5	60
R _{V1}	T	-5 - 15	140	5	125
H ₁₁	C	-23 - 73	100	23	28
H ₁₂	C	-26 - 67	100	26	33
H _{V1}	T	-5 - 15	200	5	185
V ₁₁	C	0 - 62	100	5	38
V ₁₂	C	-15 - 79	100	15	21
V ₁₃	C	-32 - 14	100	32	86
SEGMENT 2:					
R ₂₁	C	0 - 20	50	5	30
R ₂₂	T	0 - 6	140	5	140
H ₂₁	C	-22 - 42	100	22	58
H ₂₂	C	0 - 81	100	5	19
H ₂₃	T	0 - 3	140	5	140
V ₂₁	C	-12 - 0	50	12	50
V ₂₂	C	0 - 68	100	5	32
V ₂₃	C	0 - 50	100	5	50
V ₂₄	C	-14 - 0	50	14	50
V ₂₅	T	0 - 60	200	5	200
SEGMENT 3:					
R ₃₁	C	0 - 16	50	5	34
R ₃₂	T	0 - 6	140	5	140
H ₃₁	C	-3 - 60	100	5	40
H ₃₂	C	-1 - 73	100	5	27
H ₃₃	T	0 - 4	140	5	140
V ₃₁	C	-8 - 3	50	8	47
V ₃₂	C	0 - 31	50	5	19
V ₃₃	C	0 - 16	50	5	34
V ₃₄	C	-13 - 0	50	18	50
V ₃₅	T	0 - 60	200	5	190
V ₃₆	T	0 - 96	240	5	135

TABLE 2.6

REACTIONS OF LOAD CELLS FOR APPLIED PRELOADS DETERMINED BY FINITE
ELEMENT MODEL

COORDINATES OF PRELOAD	TENSION LINK RV ₁	TENSION LINK HV ₁	TOTAL APPLIED PRELOAD	PRELOAD RANGE
x m	2.150	2.137		
y m	.050	.055		
z m	.013	.055		
<u>Applied Load</u>				
Fx N	11.55	0		
Fy N	0	53		
Fz N	20	53		
<u>Load Cell Reactions</u>				
R ₁₁ N	11.55	0.0	11.6	5 - 60
H ₁₁ N	0.0	25.8	25.8	23 - 68
H ₁₂ N	0.0	27.2	27.2	26 - 33
V ₁₁ N	4.7	5.6	10.3	5 - 38
V ₁₂ N	4.7	13.9	18.6	15 - 21
V ₁₃ N	10.6	33.6	44.2	32 - 86

2.2 Segment and Model Modifications

The three segments and the model were modified to accommodate the new pretension arrangements and facilitate the model assembly, disassembly as well as adjustments during set-up and testing. The extent of modification varied in each of the three segments and segment 3 was also modified to reduce its mass.

For segments 2 and 3 the vertical and longitudinal tension links and inserts were embedded into the segment with the free end of the tension link fitted through a hole in the bulkhead and attached to the other side of the bulkhead. The horizontal tension link was attached to the outside of the segment and the insert embedded in the model. During segment installation the free end of the tension link was fed through the hole in the end plate of the insert and attached there. In Figure 2.6 the vertical and longitudinal inserts on segment 2 can be seen while in Figure 2.7 the horizontal insert for segment 3 can be seen - embedded into the model.

Segment 1, because of its small size and the narrowness of the adjoining cavities, did not have sufficient space to mount 3 tension links. As a consequence, it was decided to use two angled tension links one in the x-z plane and one in the y-z plane. Both tension links were angled up so that they could be attached on a mounting block on the top deck as shown in Figure 2.8. The tension links were attached to the segment by screwing them into set screws which were embedded into the segment.

Another modification which was made to segment 1 was the addition of an extra load cell in the vertical direction. This brought the total number of load cells on segment 1 to six. While only five support points were needed to determine the force its components and its location, six support points were needed to support the loads. From the finite element analysis it was found that a tension link could not both act as a sixth support point and be at a correct location to apply preloads. It was decided to add a third vertical load cell which would be at the back of the segment between the other two as shown in Figure 2.9. This modification was necessary to stabilize the segment and eliminate some of the problems observed earlier.

In segment 2, a minor modification was implemented by reducing the number of vertical load cells. In earlier tests, it was observed that it was difficult to accurately adjust the preloads on the two rear vertical supports. By examination it was found that because the two support points were too close, the removal of one of them would alleviate this problem. Therefore, the rear vertical load cell V24 was removed and a new 100N load cell replaced the 50N load cell at position V21. (This modification took place after the preliminary calibration and testing of segment 2 but before the final calibration).

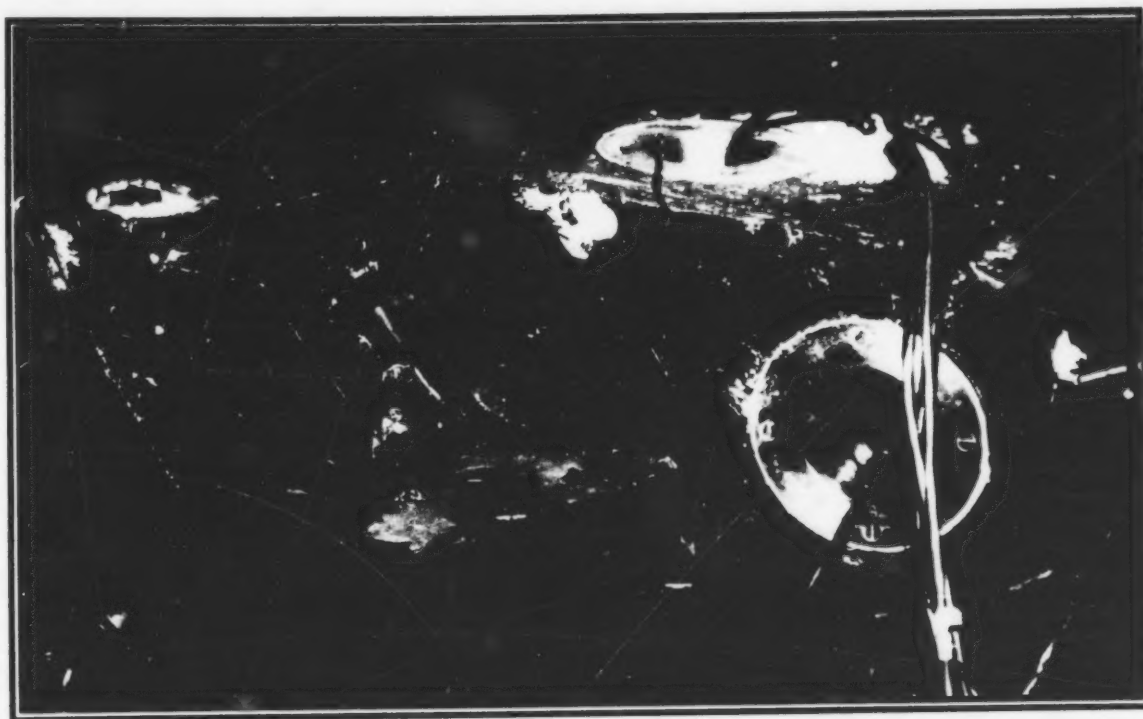


Fig 2.6 VERTICAL & LONGITUDINAL TENSION LINK INSERTS of SEGMENT 2

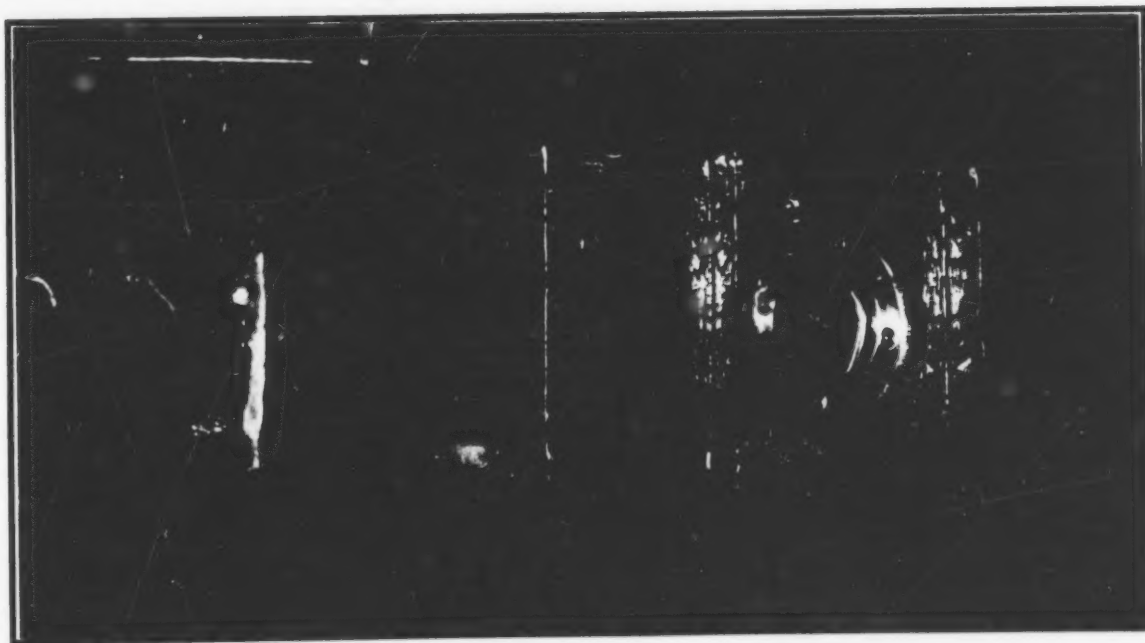


Fig 2.7 OPENING in MODEL FOR HORIZONTAL TENSION LINK INSERT of SEG. 3

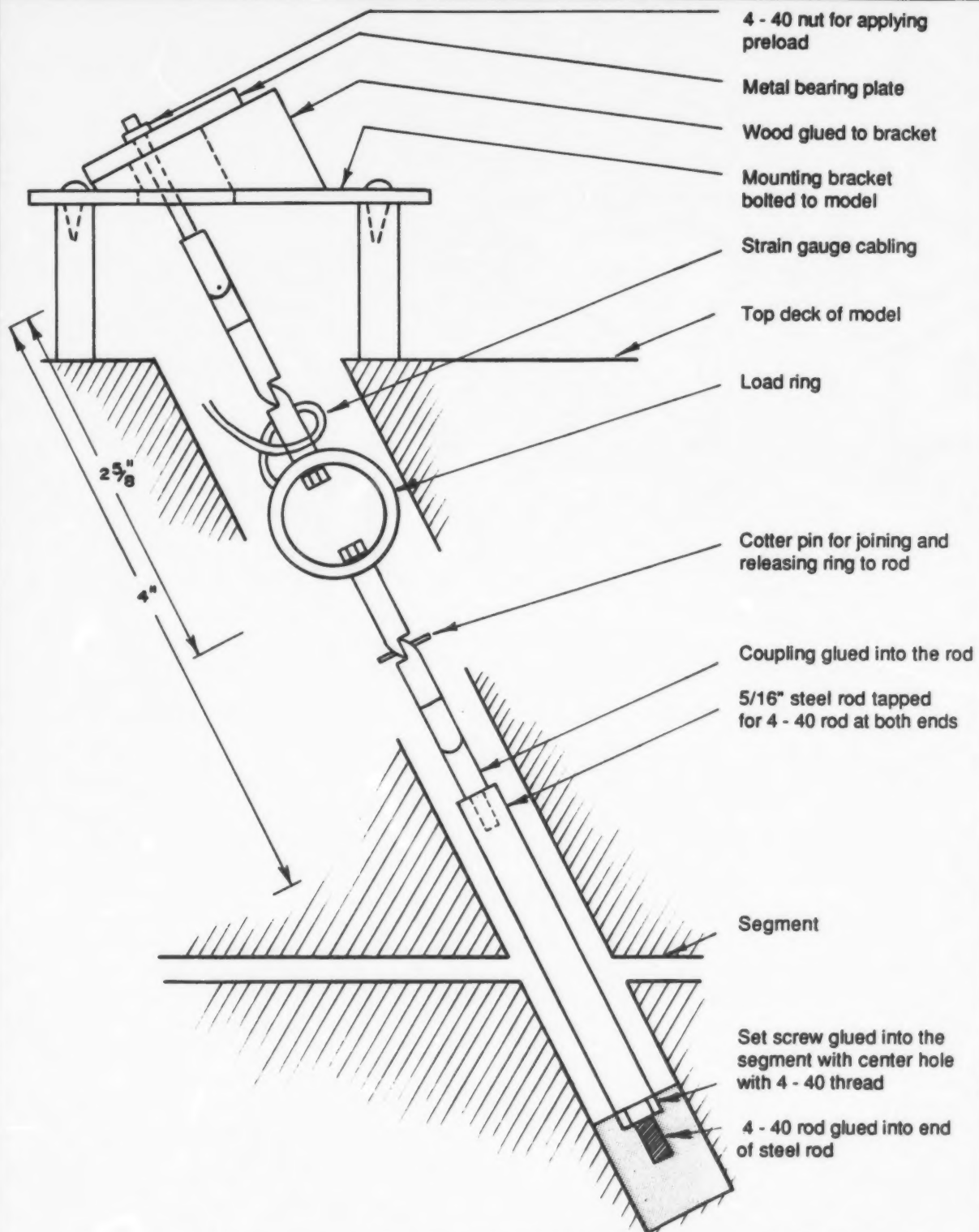


Figure 2.8 ANGLED TENSION LINK MOUNTING for SEGMENT 1

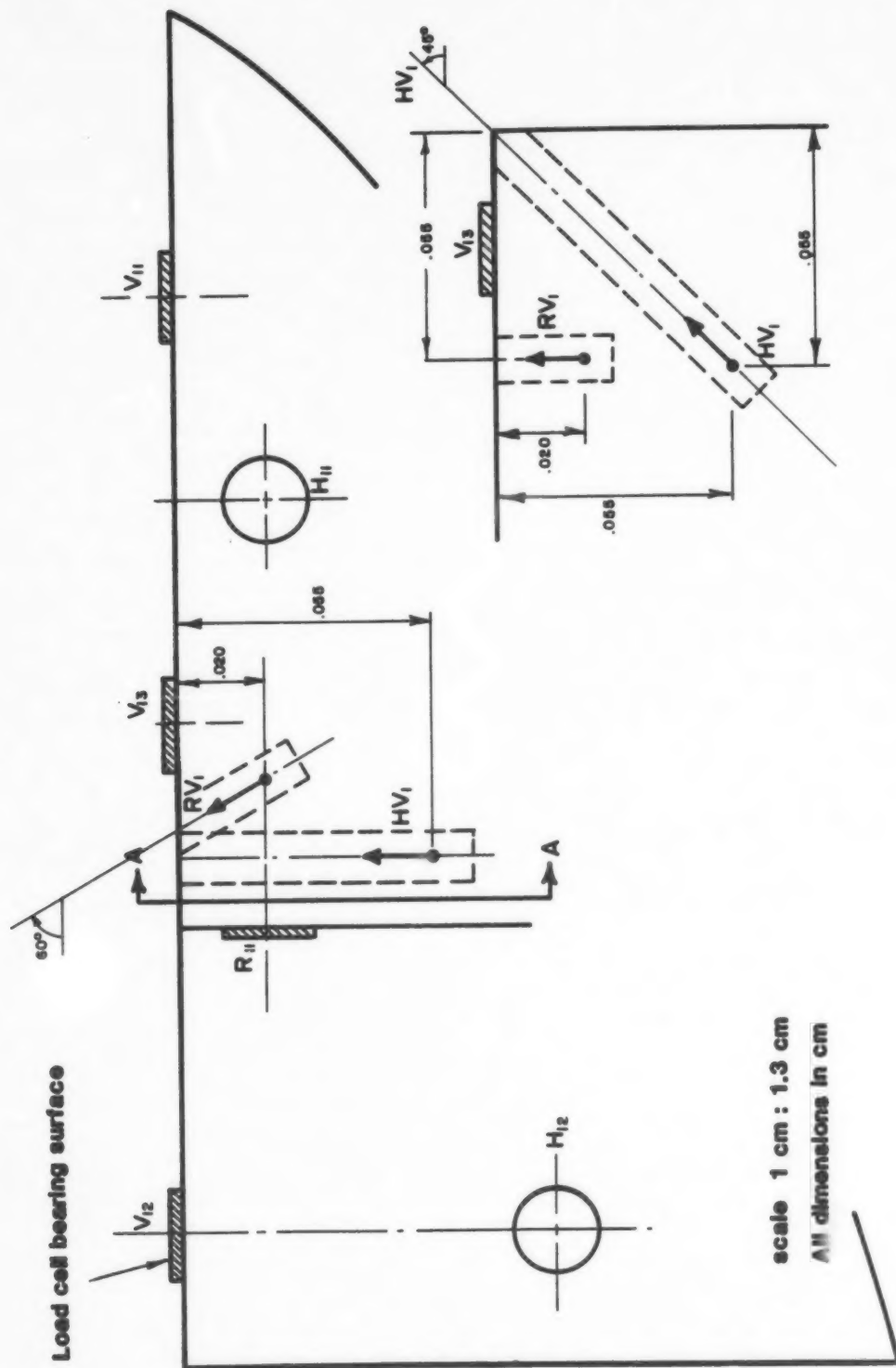


Figure 2.9 LONGITUDINAL ELEVATION of SEGMENT 1

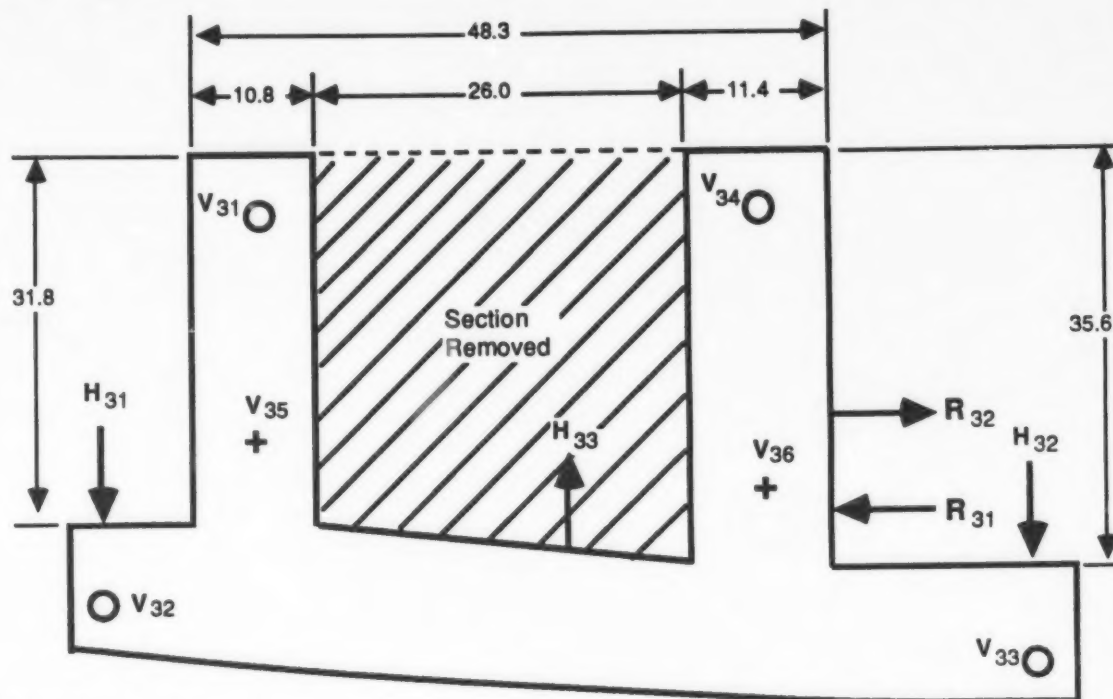
Segment 3 presented a problem because of its weight, 295N. It has been observed that inertial loads are much higher than the two other segments. For segment 3, the resolved longitudinal force is much smaller than segments 1 and 2 because of the hull angles and it is desirable to minimize inertia loading. When considering the pretensioning arrangements, it was realized that it would be quite difficult to design a tension link which could support 295N plus transducer preload during in-air calibrations and not be substantially stiffer than the load cells. The two problems were solved by reducing the segment weight. A box was cut out of the back of segment 3 as shown schematically in Figure 2.10 and as implemented in Figure 2.11. To reduce the mass of water entrapped in the segment cavity, and hence undesirable hydrodynamic loading, a corresponding box was attached to the model as shown in Figure 2.7. One half inch clearance was left between the segment and the box. The effect of the modification was to cut the weight of segment 3 by half to 150N with only a slight increase in the added mass. Since the center of the segment was cut out - two vertical tension links had to be used one on each side of the segment, with both lying on the same line as the center of gravity.

2.3 Accuracy of Load Support Surfaces

In order to measure forces at all segment mounting locations it is necessary for the measurement planes to be mutually perpendicular to each other. It is also necessary for all transducers in a given plane to measure on axes which are parallel to a high standard of accuracy.

The effect of misalignment of the measuring cells can be observed for two separate cases: misalignment of the transducer and misalignment of the bearing surface. In the first case, referring to Figure 2.12, the axis of the load cell is not normal to the measurement plane. As a result the transducer can only measure the component $P_1 \cos \theta$ of the total load; however, this misalignment has no effect on other measuring locations because of the independence of load support points. To achieve load measurement accuracy of $\pm 1\%$, θ must be less than 5.7° . This is a fairly large tolerance on the squareness of the surfaces, and can easily be achieved. Hence, this case of misalignment is not critical to the accuracy of measurement.

The second case of misalignment occurs if the transducer is assumed to be correctly aligned, but the bearing surface is misaligned. The force exerted on the segment by the transducer is normal to the bearing surface. In this case, as shown in Figure 2.12, the force measured by transducer 2 is not affected; however, a significant error is caused in the measurements made in the remaining two perpendicular planes. The second component of the reaction force at the misaligned bearing surface is balanced by a force at the transducer measuring parallel to this force. The magnitude of this force is $P_2 \tan \beta$ which requires alignment to an accuracy of 0.5° for one percent error.



All dimensions in cm.

Figure 2.10 SEGMENT 3 PLAN SHOWING SECTION REMOVED

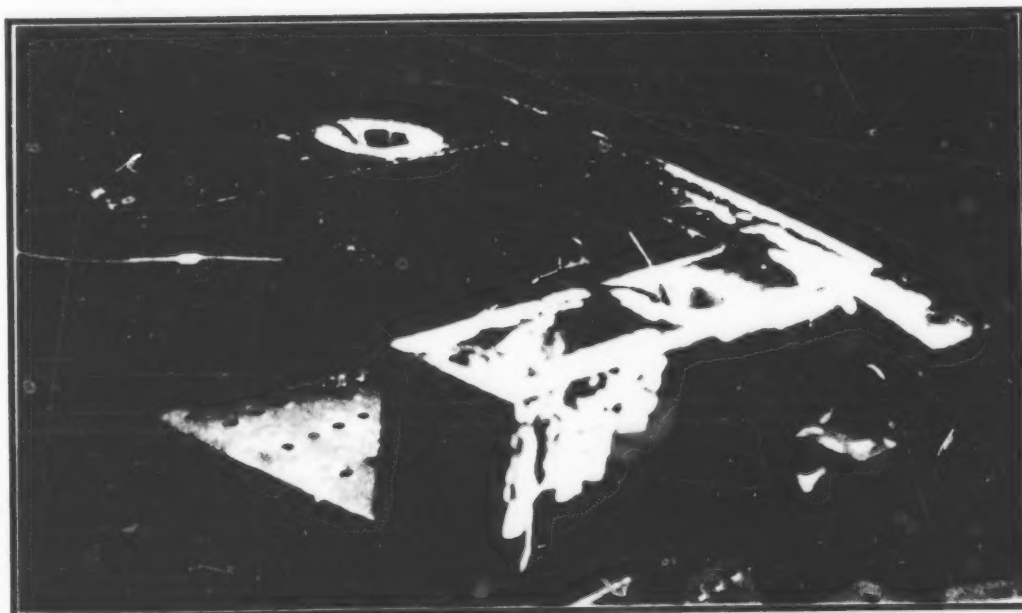


Figure 2.11 SEGMENT 3 AFTER MODIFICATIONS

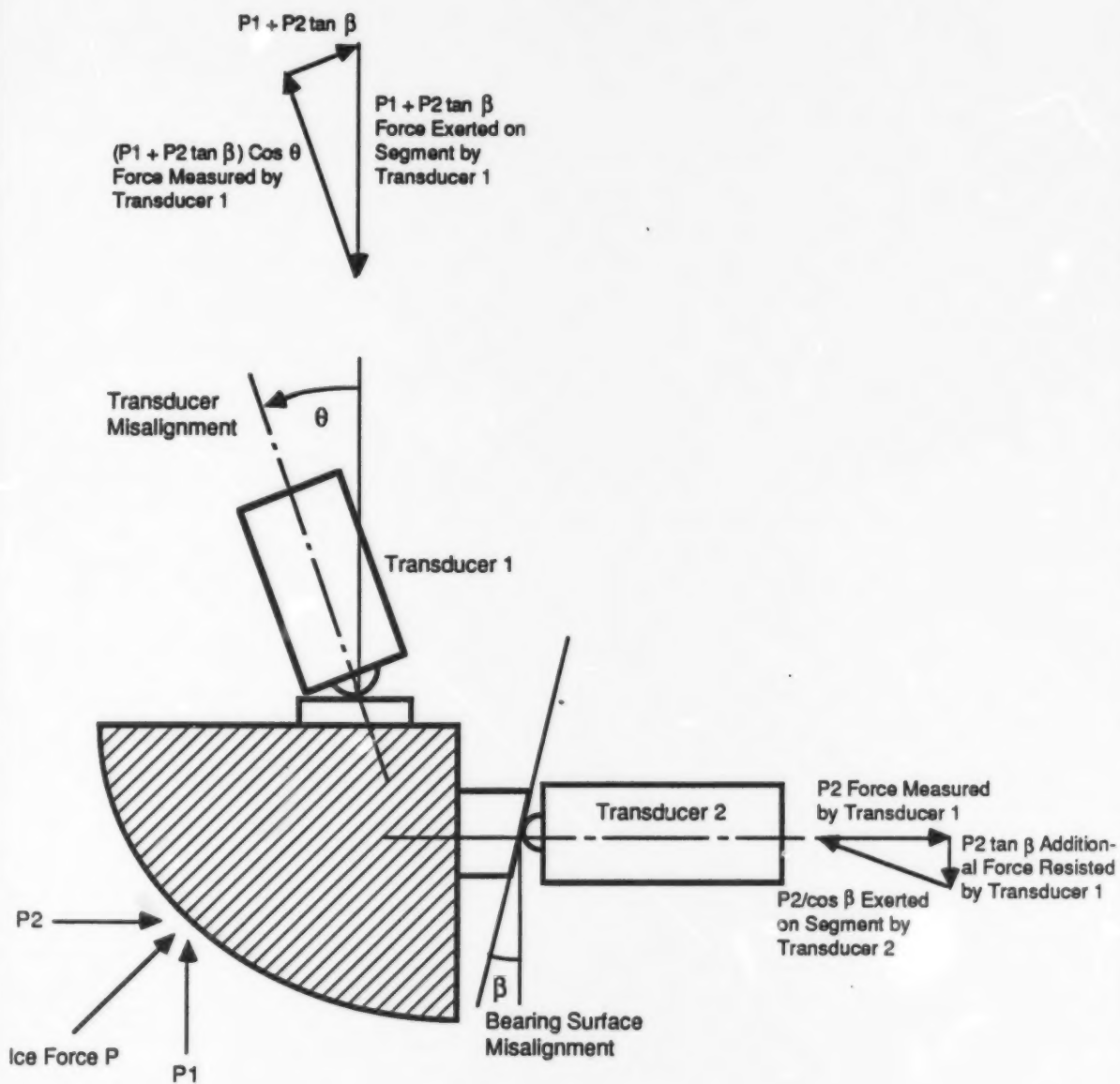


Figure 2.12
EFFECT of TRANSDUCER and BEARING SURFACE MISALIGNMENT

This analysis shows that a critical factor in measuring forces on the segment is the alignment of the bearing surfaces. A misaligned bearing surface, nominally normal to a force component exerted on the segment will cause a significant force on a transducer perpendicular to the force component. This effect would make the segment extremely difficult, if not impossible to calibrate. In order to successfully calibrate the segment all bearing surfaces must be machined to an accuracy of better than ± 0.5 degrees.

In order to correctly machine the bearing surfaces, jigs were constructed for each of the three segments in order to define the direction of the segment axis for machining the bearing surfaces. These jigs were constructed from full size drawings of the model using sections from the body plan. Two sections were used for each segment, for Segment 1 these were taken at stations 9.75 and 10.23, for segment 2 at station 9 and 9.5, and for segment 3 at stations 7.5 and 8.5. In each case the section profile was transferred to the jig material to create a template. These templates were then mounted into frames which held them in the correct orientation, perpendicular to both the baseplane and centerplane of the model. The segment 2 jig formed by the frame and the template is shown in Figure 2.13.

In order to create a reference plane which could be used to machine the bearing surfaces flat, fixtures were attached to the segments. In the case of segment 1, because of its unusual shape the fixture was a plate which was placed under the segment and attached through a framework to both sides of the segment as shown in Figure 2.14. The fixtures for segments two and three consisted of plates screwed to the bottoms of the segments. The alignment of the plates under all three segments could be adjusted relative to surfaces on which they were sitting by means of round head screws, screwed into the bottom of each plate. During machining these screws sat on the milling machine bed. By adjusting the level of the plate the alignment of the entire segment could be adjusted.

In order to set the alignment of each segment its jig was positioned with the template profiles aligned along the stations marked on the segment surface. The jig was then clamped in position so that the axis marked on the jig were parallel with the segment axis as defined by the segment surface. The screws under the segment were adjusted so that the jig axis became level, as indicated by spirit levels, and the screws were locked in position. The alignment of the segment relative to a longitudinal axis was determined by measuring horizontally from the baseplate fixture to the jig. By following this procedure for each segment it was possible to align the segments correctly in the milling machine.

The accuracy of this alignment method was estimated to be in the order of $\pm 1^\circ$, primarily because the sectional profiles measured on the segments were not completely identical to those lifted from the lines plan. The segments tended to be slightly more convex than the section profiles indicated that they should be.



Figure 2.13 **SEGMENT 2 JIG and TEMPLATE**



Figure 2.14 **SEGMENT 1 in MACHINING FRAME**

3.0 DATA ACQUISITION, REDUCTION AND ANALYSIS

3.1 Introduction

The segment support system described as modified in section 2, serves two primary functions. Firstly, it supports and stabilizes the segments so that they behave in a manner similar to a rigid hull which does not interfere with the icebreaking process. Secondly, the system serves as an instrumentation system. At each support point there is a unidirectional load cell or tension link which are used to measure the reaction at each support point at any time during the interaction with ice. The measured reactions at the support points are then reduced using the methodology outlined earlier [1] to determine the magnitude, position and direction of the external loads acting on each segment during the interaction. This provides the position coordinates on the hull, which automatically define the hull angles and the normal direction at this position, the normal ice force, the frictional force component, hence the friction coefficient, and finally the direction along which the friction force acts. All these variables are determined as time series or they may be averaged over a given interval.

Since the analysis is performed in the model coordinate system, it is appropriate to define the coordinate system and confirm the coordinates of the load support points.

A left hand coordinate system has been used to describe the position of the transducers and to describe the position and direction of action of the forces. As shown on Figure 3.1 the origin of the coordinate system is the intersection of the centreline bulkhead, the 24.75 ft waterline and the midship plane. The 24.75 ft was chosen as the origin of the z axis since the top edges of the segments are on this waterline.

The load measurements made at each transducer have been labelled R, H or V depending whether they are in the longitudinal, horizontal or vertical directions; respectively. Each load measurement has two numeric subscripts, the first indicates the segment number and the second indicates the transducer number.

The position of the load measurements made from the transducers on each segment are shown in Figure 3.2 along with the coordinates of the transducers. No measurement of position is given for the coordinate along the line of action of the transducer. The load measurement positions, i.e. the transducer contact point coordinates have been re-measured after segment modifications and are given in Table 3.1. Some coordinates were found to differ from earlier reported coordinates prior to modification. The new coordinates supersede those reported earlier [1].

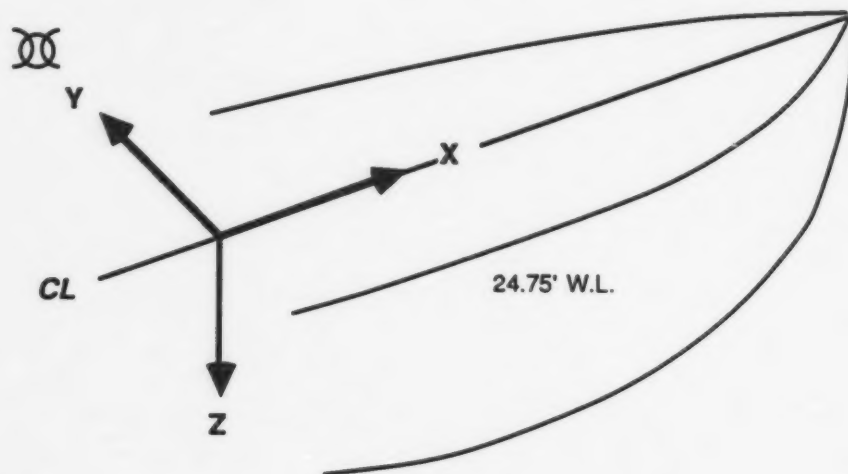


Figure 3.1 MODEL COORDINATE SYSTEM

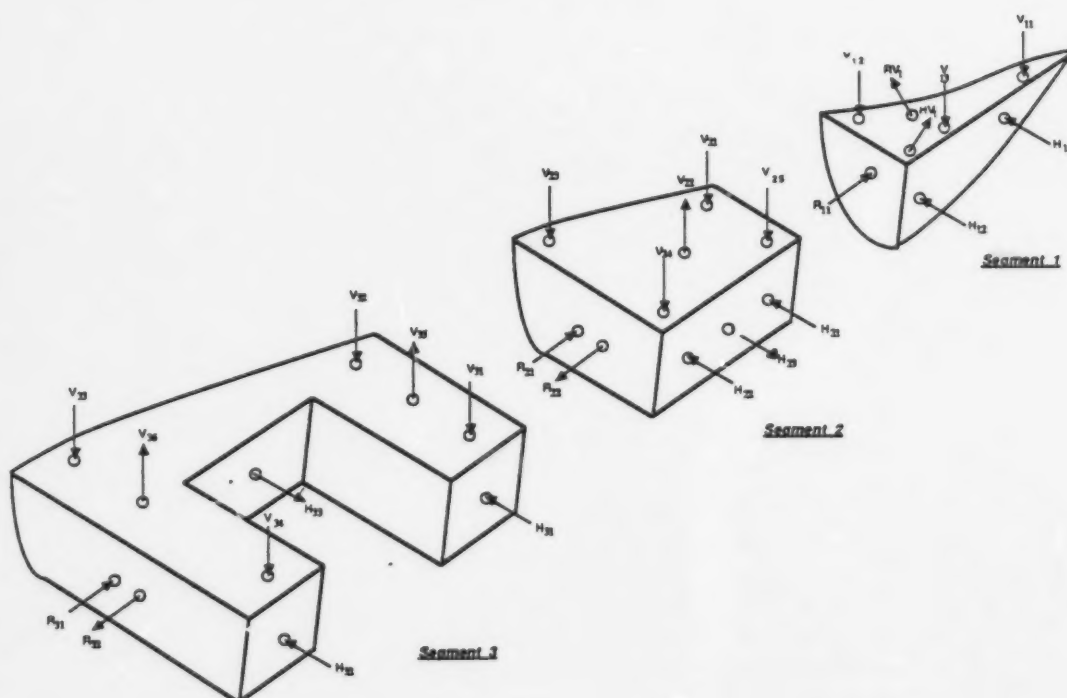


Figure 3.2 SEGMENT SUPPORT SYSTEM

TABLE 3.1

POSITIONS OF LOAD MEASUREMENTS

ORIGIN OF COORDINATE SYSTEM AT INTERSECTION OF MODEL CENTRELINE
MIDSHIP PLANE AND 24.75 FT. WATERLINE

SEGMENT 1	X m	Y m	Z m
R11	-	0.050	0.020
H11	2.219	-	0.020
H12	2.055	-	0.083
V11	2.255	0.025	-
V12	2.056	0.153	-
V13	2.165	0.020	-
RV1	2.160	0.050	0.020
HV1	2.137	0.055	0.055
SEGMENT 2			
R21	-	.122	0.075
R22	-	.068	0.075
H21	2.005	-	0.080
H22	1.655	-	0.080
H23	1.830	-	0.080
V21	1.870	0.040	-
V22	2.005	0.187	-
V23	1.655	0.337	-
V24	1.795	0.040	-
V25	1.821	0.159	-
SEGMENT 3			
R31	-	0.320	0.080
R32	-	0.240	0.080
H31	1.603	-	0.080
H32	0.920	-	0.080
H33	1.265	-	0.080
V31	1.467	0.040	-
V32	1.603	0.346	-
V33	0.920	0.445	-
V34	1.105	0.040	-
V35	1.472	0.240	-
V36	1.095	0.305	-

3.2 Data Acquisition System

Figure 3.3 describes the segmented model instrumentation and main components of the data acquisition system. The following measurements were recorded during testing.

- a) All force components of segment loads as measured by the 28 transducers. Each channel is signal conditioned prior to further processing using Vishay 2100 series signal conditioning amplifiers.
- b) Total resistance of the ice measured by a standard force block. This channel also went through a signal conditioner.
- c) Model speed and position.

Twenty-five of the transducer signals and the speed could be recorded on magnetic tape using a 28-channel Honeywell Model 5600E FM tape recorder.

A low pass filter frequency of 1 Hz was selected on the basis of earlier results for filtering the transducer signals before they were converted to digital signals.

With thirty-one channels, the analog to digital converter is able to operate at scanning rates up to 60 Hz. This scanning rate was deemed appropriate for the present application. The digitized data is passed from the converter to the computer where it is stored on a mass storage device for later retrieval and further processing.

The data acquisition software after collecting and processing the data can plot the time history of each signal, calculate basic statistics on each signal, calculate and subtract a zero value from each signal measurement and allow selection of a user defined time history interval for further plots, statistics and use in other data analysis routines. The software also stores each signal in a separate file on a selected mass storage device. This means further data processing subroutines can easily be developed for additional analysis of the signal time histories. A listing of the data acquisition software is given in Appendix A.1.

3.3 Segment Force Analysis

3.3.1 Basic Formulations

The equilibrium equations outlined on pages 68-73 of Phase I Report [1] with the directions of $\vec{n}$, the normal unit vector and $\vec{e}$, the friction unit vector defined as shown in Figure 3.4 have been used as the basis for the solution of the force components.

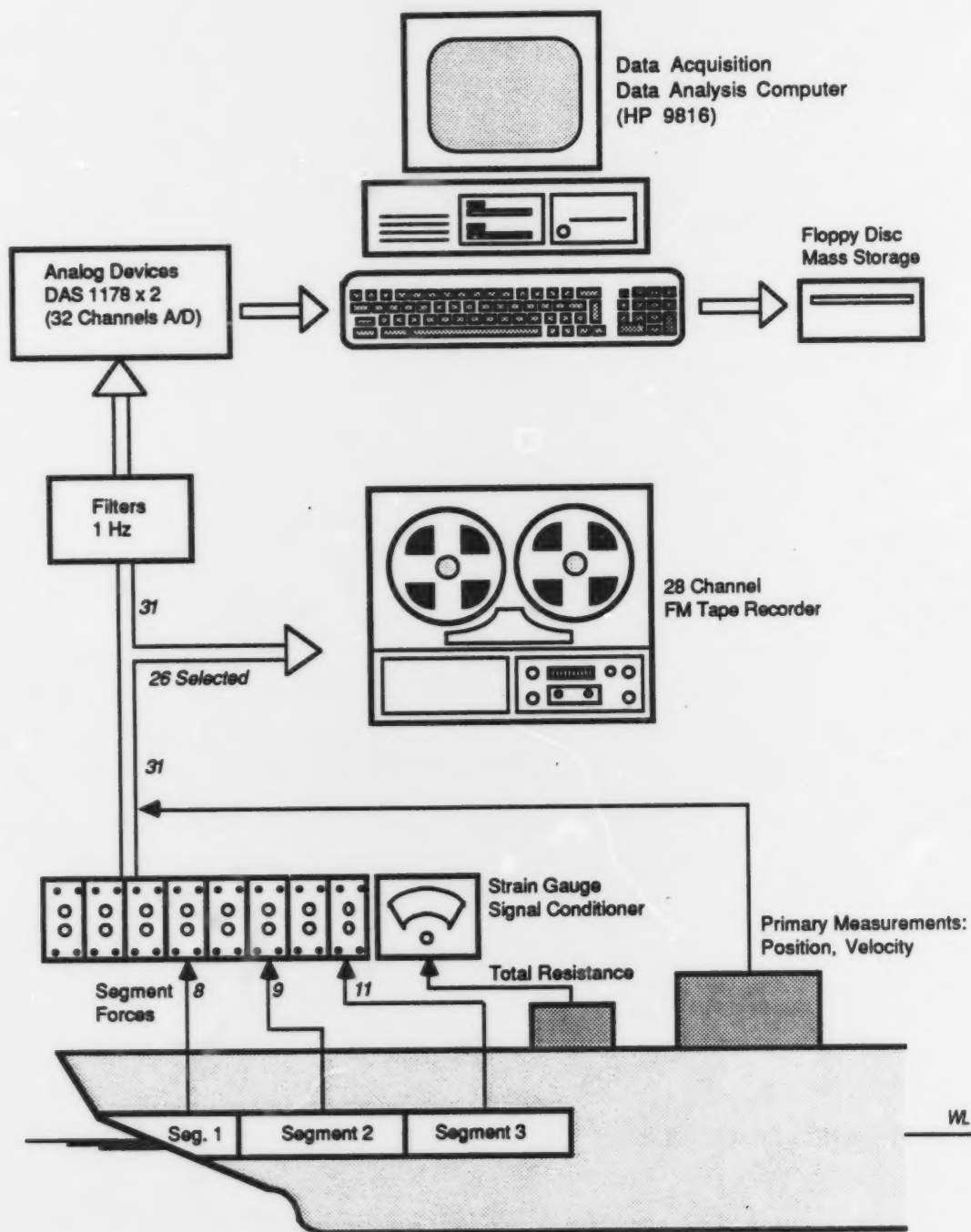


Figure 3.3 SEGMENTED MODEL INSTRUMENTATION

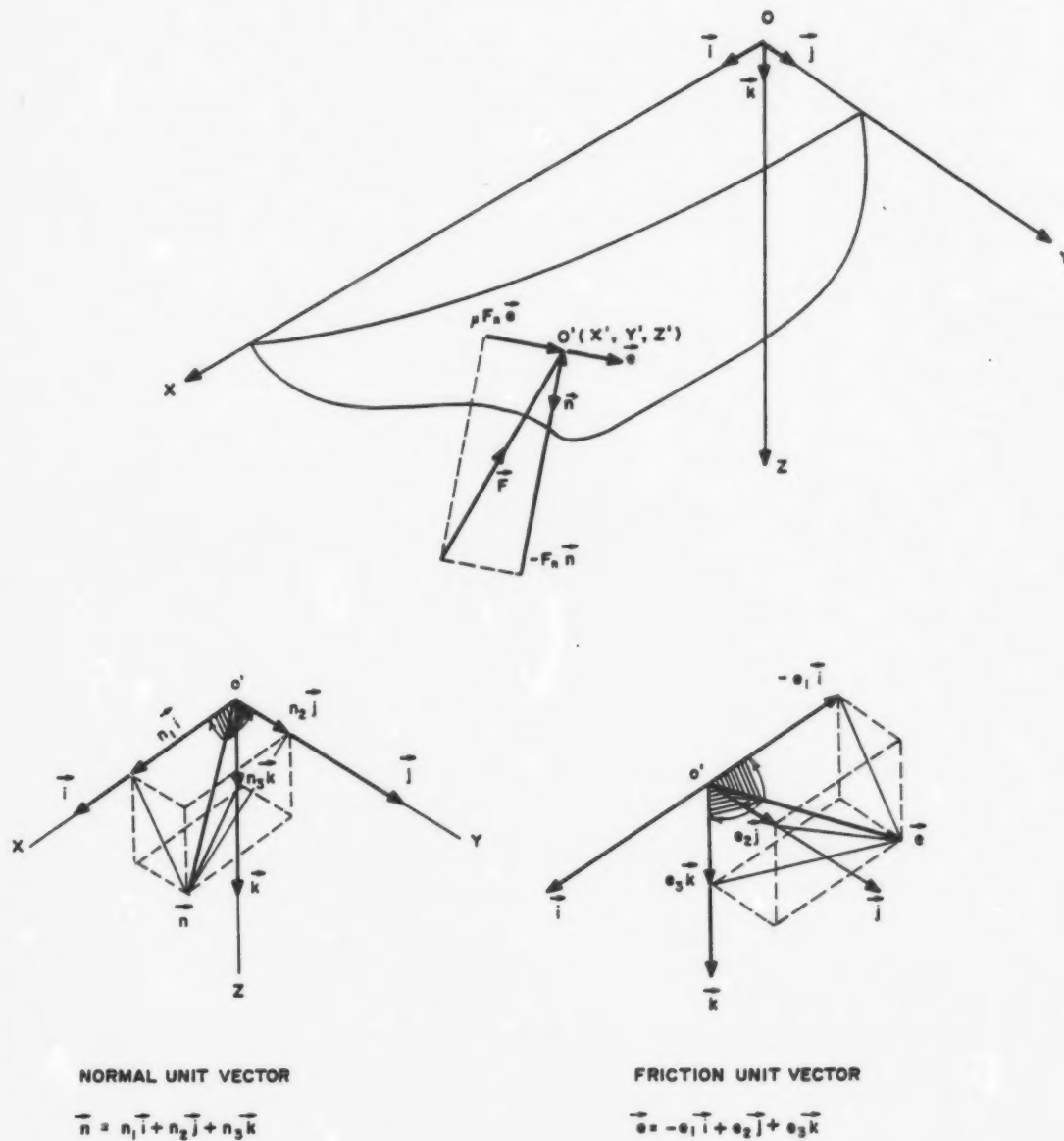


Figure 3.4 BASIC FORCE ANALYSIS (from [1])

The external normal force as shown in Figure 3.4 is $-F_n \vec{n}$ which is negative since it always opposes the normal unit vector $\vec{n}$. The external friction force is $\mu F_n \vec{e}$ where $\vec{e}$ is the unit friction vector and is defined as:

$$\vec{e} = -e_1 \vec{i} + e_2 \vec{j} + e_3 \vec{k} \quad (3.1)$$

The unit friction vector is tangential to the hull and normal to $\vec{n}$. Combining the normal and friction force the total force $\vec{F}$ is:

$$\vec{F} = -F_n \vec{n} + \mu F_n \vec{e} \quad (3.2)$$

In scalar form the x, y, z components of the force are:

$$F_x = -F_n (n_1 + \mu e_1) \quad (3.3a)$$

$$F_y = -F_n (n_2 - \mu e_2) \quad (3.3b)$$

$$F_z = -F_n (n_3 - \mu e_3) \quad (3.3c)$$

The equilibrium force equations are:

$$\Sigma R_{ij} = F_n (n_1 + \mu e_1) \quad (3.4a)$$

$$\Sigma H_{ij} = F_n (n_2 - \mu e_2) \quad (3.4b)$$

$$\Sigma V_{ij} = F_n (n_3 - \mu e_3) \quad (3.4c)$$

By combining the force equilibrium equations, a formula for F_n can be derived:

$$F_n = n_1 \Sigma R_{ij} + n_2 \Sigma H_{ij} + n_3 \Sigma V_{ij} \quad (3.5)$$

By combining the force and moment equilibrium equations defined in [1] the position of F_n can be found. The moment equations can be written as:

$$C_1 = (\Sigma H_{ij}) \cdot z' - (\Sigma V_{ij}) \cdot y' = \Sigma (H_{ij} \cdot z_{ij}) - \Sigma (V_{ij} \cdot y_{ij}) \quad (3.6a)$$

$$C_2 = (\Sigma V_{ij}) \cdot x' - R_{ij} \cdot z' = \Sigma (V_{ij} \cdot x_{ij}) - \Sigma (R_{ij} \cdot z_{ij}) \quad (3.6b)$$

$$C_3 = (\Sigma R_{ij}) \cdot y' - (\Sigma H_{ij}) \cdot x' = \Sigma (R_{ij} \cdot y_{ij}) - \Sigma (H_{ij} \cdot x_{ij}) \quad (3.6c)$$

where x' , y' , z' are the coordinates of F_n , and C_1 , C_2 , and C_3 are the external moments applied to the segments which must equal the moments at the support points for equilibrium.

It is possible that with these 4 equations (3.5, 3.6 a-c) the four unknowns, F_n , x' , y' and z' can be solved for. However, since the position of the external force must be on the model hull, it is determined by any two coordinates, e.g. x' and z' , and one of the equations is redundant. Hence, an iterative solution using two of the three equations and knowledge of the hull lines can be used to determine x' , y' and z' . Once x' and z' are known the normal unit vector n at this point on the hull surface can be determined from the hull lines plan and F_n solved for using equation (3.5).

The friction coefficient μ , and friction vector e , may then be determined from rewriting the force equilibrium equations and using the unit vector definition:

$$\mu e_1 = \frac{\Sigma R_{ij}}{F_n} - n_1 \quad (3.7a)$$

$$-\mu e_2 = \frac{\Sigma H_{ij}}{F} - n_2 \quad (3.7b)$$

$$-\mu e_3 = \frac{\Sigma V_{ij}}{F} - n_3 \quad (3.7c)$$

$$\mu = \sqrt{(\mu e_1)^2 + (-\mu e_2)^2 + (-\mu e_3)^2} \quad (3.8)$$

Then the friction vector is determined by:

$$e_1 = \frac{1}{\mu} \left[\frac{\sum R_{ij}}{F_n} - n_1 \right] \quad (3.9a)$$

$$e_2 = - \frac{1}{\mu} \left[\frac{\sum H_{ij}}{F_n} - n_2 \right] \quad (3.9b)$$

$$e_3 = - \frac{1}{\mu} \left[\frac{\sum V_{ij}}{F_n} - n_3 \right] \quad (3.9c)$$

3.3.2 Iterative Procedure for Determining Force Position

The iteration procedure used to determine x' , y' and z' , the location of the force on the model surface, may be outlined as follows:

1. assume an initial z and solve for x in equation (3.6b). The initial value for z used was 0.0267 corresponding to the 23' W.L.
2. knowing x and z find y from the lines plan at the 16', 20', 22' 23' and 24' waterlines.
3. calculate the error in C_1 at the 16', 20', 22', 23' and 24' waterlines. The error in C_1 is defined as:

$$C_{1_{err}} = \sum H_{ij} \cdot z - \sum V_{ij} \cdot y - C_1 \quad (3.10)$$

4. Find the waterline at which the error in C_1 is less than ± 0.1 . If this is not the case interpolate between the two appropriate waterlines to find the correct value of z . The interpolation assumes that y will not change significantly with a small change in z .
5. Calculate a new value of x from the new value of z and if the difference from the previous x is greater than 1mm repeat steps 3 to 5 until the values of x converge.

Examples of the iteration results for one case on segments 1 and 2 are shown in Figure 3.5.

The iteration routine is slightly different from that used in Phase I of this study where the initial value of the x-coordinate was approximated as:

$$x = \frac{\sum (H_{ij} \cdot x_{ij})}{\sum H_{ij}}$$

and all the other values of x were calculated from (3.6c). With the introduction of hull form interpolation section to the software it was possible to improve the iterative procedures.

3.3.3 Hull Form Interpolation

During various steps of the solution it is necessary to know the y coordinate on the hull and the hull angles at a given x and z value. This can be done graphically from the lines plan. However due to the amount of calculation of y that are required the hull offsets were calculated numerically using a cubic spline algorithm. A computer subroutine was written in which the x, y and z coordinates corresponding to segments 1, 2 and 3 as determined from the lines plan were written into the computer code. This routine is called the "hull interpolation subroutine" and is listed in Appendix A.2.

The value of y at any point on Segments 1, 2 and 3 can be determined by numerically fitting a waterline of buttock curve through the appropriate stored points and finding the position of the y value required on the curve. Values of the waterplane angle α and the flare angle β were determined from the slope of the fitted curves. Table 3.2 compares values of y and hull angles α and β found directly from the lines plane to those found from the hull interpolation subroutine.

3.3.4 Friction Direction

The counterclockwise angle from the horizontal of the friction vector $\vec{e}$ can be used to describe the direction of the friction force. The angle which will be called ψ (Psi) is the projected angle of the friction vector on the centreplane of the model. It is positive moving counter clockwise from a horizontal plane as shown in Figure 3.6. It is defined as

$$\psi = \tan^{-1} \left(\frac{e_1}{-e_3} \right)$$

When e_1 is positive and e_3 is positive then ψ has a value between 0° and -90° and acts down and aft.

Figure 3.5 Example of the Iterative Procedure for Determining the Force Position

Segment 1	x, m	z, m	y, m	error in C_1
first x using $z = 0.0267$ m	2.2519			
		0.0720	-.0229	0.0239
		0.0420	0.0351	-0.6468
interpolate to find z at zero error in C_1 then interpolate to find y at z		0.0709	-0.0208	0.0
y cannot be negative, interpolate to find z at $y = 0$		0.0601	0.0	-
new x using $z = 0.0601$ m	2.2579			
		0.0720	-0.0268	0.0540
		0.0420	0.0322	-0.6243
interpolate to find z at zero error in C_1 then interpolate to find y		0.0696	-0.0221	0.0
y cannot be negative so interpolate to find z at $y = 0$		0.0584	0	-
new x using $z = 0.0584$ m	2.2576			
less than 0.001 difference in last two values of x: calculate normals, force components and friction direction.				
% error in $C_1 = -0.375$ % error in $C_2 = 0.0$ % error in $C_3 = 0.494$ Results: $F_n = 10.5$ N $x = 2.258$ m $z = 0.058$ m $\alpha = 29.5^\circ$ $\beta = 52.7^\circ$ $F_f = 2.4$ N $\psi = 148^\circ$ (down and forward) <i>force is on the edge of the segment so ψ is extremely hard to predict.</i>				
Segment 2	x, m	z, m	y, m	error in C_1
first x assumes $z = 0.0267$ m	1.0208			
		0.0720	0.4665	1.482
		0.0420	0.4710	-2.542
interpolate to find z at zero error in C_1 then interpolate to find y		0.610	0.4682	0.0
new x using $z = 0.0610$ m	1.0778			
		0.0720	0.4618	1.5439
		0.0420	0.4669	-2.542
interpolate to find z at zero error in C_1 then interpolate to find y		0.0605	0.4638	0.0
new x using $z = 0.0605$ m	1.0771			
less than 0.001 difference in last two values of x: calculate normals, force components and friction direction.				
% error in $C_1 = 0.0$ % error in $C_2 = 0.0$ % error in $C_3 = -0.529$ Results: $F_n = 133.5$ N $x = 1.077$ m $z = 0.061$ m $\alpha = 5.1^\circ$ $\beta = 17.8^\circ$ $F_f = 17.8$ N $\psi = -53^\circ$ (down and aft)				

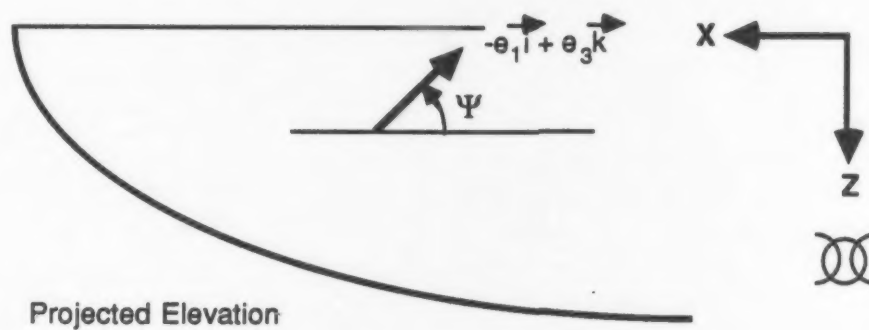


Figure 3.6 **DEFINITION OF FRICTION DIRECTION Ψ**

TABLE 3.2

COMPARISON OF INTERPOLATED HULL ANGLES TO ACTUAL HULL ANGLES
(for stations on the 23' WL, $Z = .027m$)

STATION	X m	WATERPLANE ANGLE		FLARE ANGLE	
		LINES PLAN	HULL INTERPOLATION SUBROUTINE	LINES PLAN	HULL INTERPOLATION SUBROUTINE
7	.879	3.5	.8	7	7.3
7.5	1.099	5.5	4.9	10	10.6
8	1.319	8.5	9.2	12.5	14.0
8.5	1.539	14.5	15.6	22	23.1
9.0	1.759	23	22.9	33	33.2
9.5	1.979	28	28.9	43	44.4
10	2.198	29	30.8	50	53.4

4. CALIBRATION PROGRAM AND APPARATUS

4.1 Overview of Calibration Program

The calibration program consisted of several levels of calibrations as shown in Figure 4.1 to insure that the system was fully calibrated and to eliminate uncertainties at each level of the model instrumentation.

The calibrations necessarily started with the load transducers of which there were two types - the load cells and the tension rings. The load cells had been fully calibrated once before as described in Phase I Report [1] but a re-calibration was necessary to check the performance of the load cells and to document any changes in their linearity and hysteresis.

An additional requirement was to address the cross-sensitivity of the load cells to a moving bearing surface. During ice testing the ball bearing is resting on the segment. Since the segment must move in response to the load, it will move underneath the load cells and could possibly transmit a frictional force to the load cell if the bearing slides on the segment. In theory the load cell should not carry any frictional loads or measure them. A test was desired to determine the actual behaviour of load cells when loaded on a moving surface.

The other transducers are the tension rings, which can only be loaded in tension. Since these were completely new transducers a calibration was necessary to determine their response.

The next level of calibration is the segment calibrations. After documenting the conversion factors, linearity and hysteresis of the transducers, they were installed on the segments. Now the segment becomes a transducer in effect, translating and rotating minutely in all three directions to transfer the loads to the support points.

Because this behaviour is quite complex, segment calibrations are needed to document segment behaviour. Ideally when a load is applied to the segment the segment transducers will record the same loads that would be measured if the external force could be broken into components and directly applied to the transducers. However, the segment physically separates the transducers from the load and the loading of the transducers is determined by the minute movements and rotations of the segment as it is loaded. The deviation of the segment from the ideal as well as linearity and hysteresis must be known before utilization of the segment can begin. Since the model is tested in water the calibrations must be relevant to the in-water behaviour of the segments. As well the pretension loads of the transducers had to be verified to determine if they were adequate. The design load 75N had to be applied at the segment extremities to check that the load cells remained in contact with the segment.

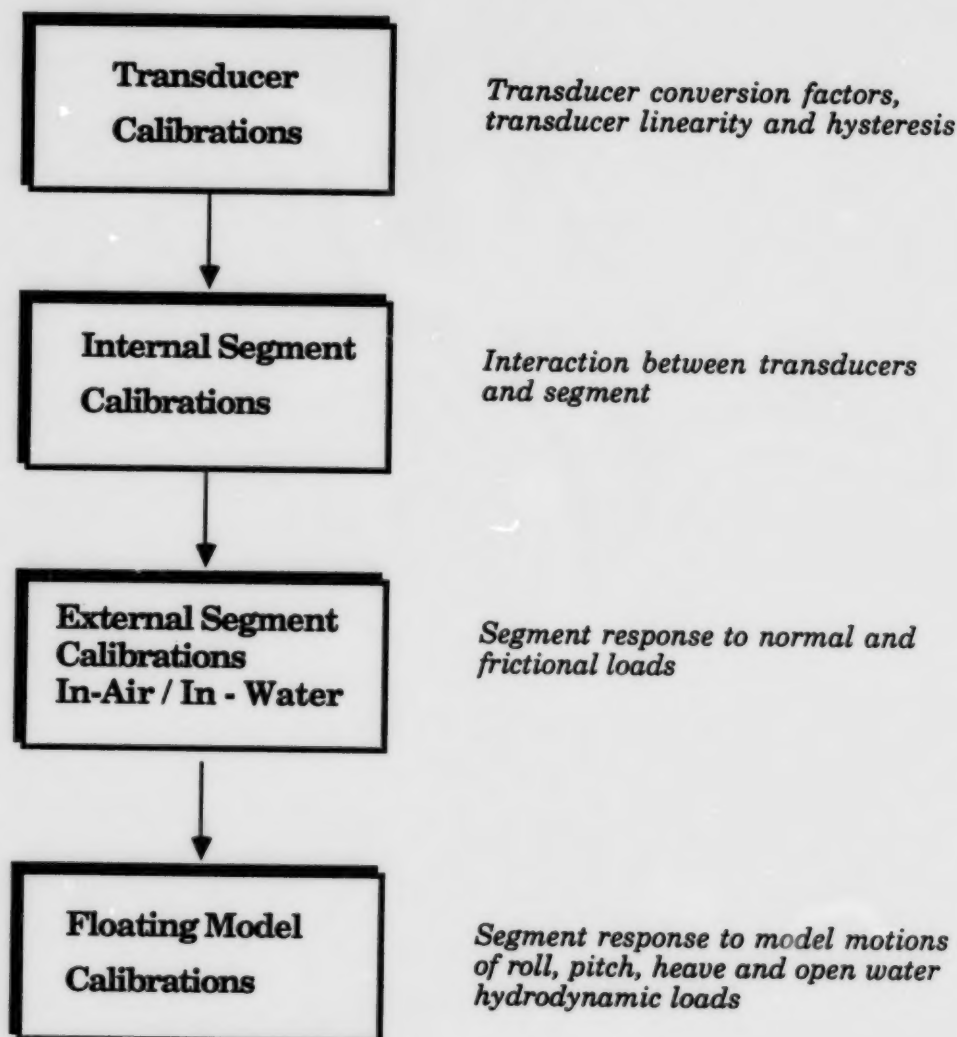


Figure 4.1 MODEL CALIBRATION PLAN

Three types of calibrations were possible with the segments: internal, external in-air, and external in-water.

The segment transducers could be adjusted so that they applied an imbalance load on the segments and therefore on the other transducers. This would document transducer interactions.

External in-air calibrations would involve applying loads to the segment surface at a known position and orientation to the hull. This would be done with the segment and model in-air and the segment weight carried by increased pretension on the tension links. The weight of the segment could interfere with its response.

In-water calibrations would follow basically the same procedure as the in-air calibrations except that the model would be in the water, correctly ballasted at the test waterline. In this case the segments are neutrally buoyant so their weight is not a factor in the segment response and therefore they will probably be better behaved.

In-air calibrations are not required if the segment can be rigorously calibrated in-water. However the in-water calibrations will necessarily be time consuming and difficult because the point of load application will be underwater and it will be hard to fix the model relative to the calibration load. Therefore, if both in-air and in-water calibrations are performed and comparison of the two can be made. If the comparison is favourable perhaps rigorous calibrations need only be carried out in-air with a few "checks" made with the model in the water.

The third level of calibrations is the segment response to open water hydrodynamic loads and to motions of the model (pitch, roll, heave). These are necessary so that they may be subtracted from the net segment response to determine the ice loading.

The procedure and apparatus for conducting each of these calibrations and the results is discussed in this and the next chapter.

4.2 Load Cell Calibrations

All of the load cells to be used in segment 1, 2 and 3 were recalibrated. Dead weights were used to re-calibrate the load cells. The calibration arrangement is shown on Figure 4.2. Each load cell was assigned to its own electrical cable and Vishay signal conditioner so that the instrumentation of each load cell was the same as it will be when the load cells are installed in the model. Excitation and gain was also set at the values to be used during the tests.

The load on each load cell was incrementally increased and then decreased to check the linearity and hysteresis of the load cells. The calibrations indicated that some of the load cells had been damaged, either during the previous testing or while in storage. The measuring diaphragm and gauge was replaced on these cells and the change is indicated with an "A" after the load cell serial number to indicate that it is essentially a new load cell. One load cell was damaged between ice tests 2 and 3 and its measuring diaphragm and gauge were replaced. All the load cells to be used showed excellent linearity. Conversion factors obtained compare well to the factors used during previous testing and typical results are given for segment 2 in Table 4.1. Except for gauge #119 the new conversion factors agree well with the old ones especially considering that the signal conditioner gain has been changed and instrumentation is different.

The load rings were calibrated by hanging weights vertically from the ring. Care was taken to support the strain gauge cabling so that it did not exert a load on the ring.

The calibration procedure was identical to that of the load cells with 15 points recorded for each calibration. The linearity of the load rings was excellent with very low hysteresis. Conversion factors and correlation coefficients are given in Table 4.2 for the load rings used in segment 2.

An attempt was made to determine the sensitivity of the load cells to friction. Each transducer was loaded as shown in Figure 4.3. A metal shim was placed between the load cell and the scale table and then weights were placed on the other table in order to apply a load to the load cell. A wire was attached to the end of the shim and then run through a fixed pulley so that a vertical downward force on the end of the wire would pull the shim out from under the load cell. By using this arrangement it was possible to insure that the shim did not vary its angle of inclination to the load cell as it was being pulled out from underneath it. The angle of inclination was kept as low as possible ($\approx 1^\circ$) but it would have required a much more sophisticated rig to insure that it was kept at zero. This method however, insured that θ was constant so that any upward or downward load exerted by the shim on the load cell remained constant during the test.

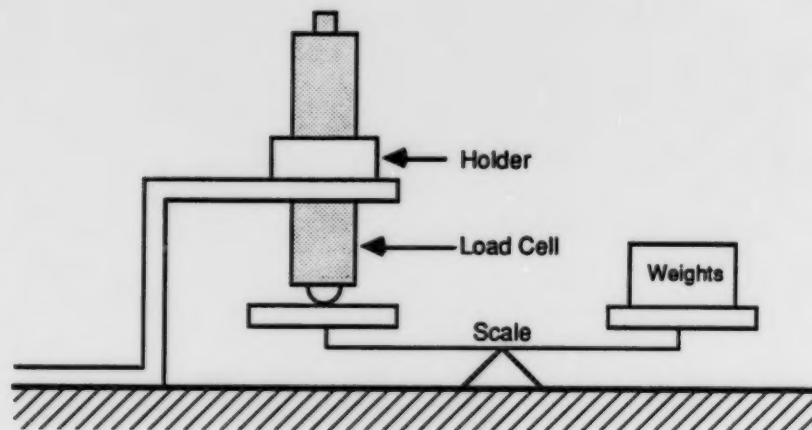


Figure 4.2 LOAD CELL CALIBRATION ARRANGEMENT

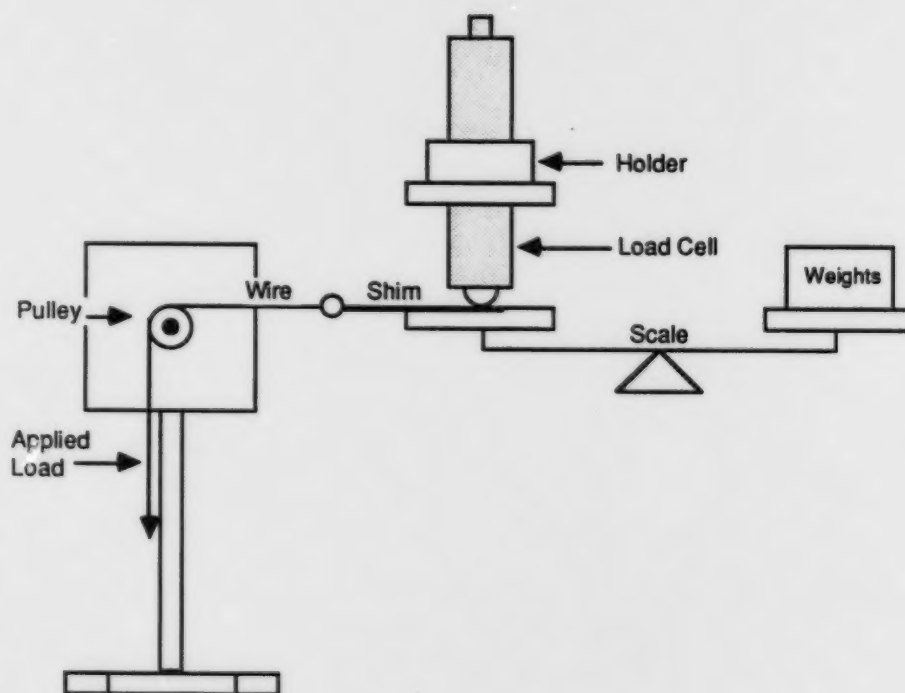


Figure 4.3 FRICTION CALIBRATION

TABLE 4.1

COMPARISON OF NEW AND OLD LOAD CELL CALIBRATION FACTORS

GAUGE NO.	OLD CAL FACTOR x 2 (from [1]) N/v	NEW CAL. FACTOR N/V	% DIFFERENCE
101	37.6	37.5	.3
102A	-	20.65	-
103	38.4	37.85	1.4
104	38.2	38.3	.3
105A	-	22.14	-
106	15.2	15.4	1.3
107	35.8	36.1	.8
108	37.2	37.4	.5
109A	-	41.0	-
110	38.9	40.1	3.0
111	38.6	38.75	.4
112	40.2	42.2	4.7
112A		41.17 (112 regauged)	-
114	38.1	39.0	2.3
115	33.8	35.2	5.0
116A	-	36.65	-
117	15.6	16.0	2.5
118	16.2	16.90	4.1
119	38.2	40.5	5.7
120	16.6	16.8	2.4

TABLE 4.2
LOAD RING CALIBRATION

POSITION	RATING (N)	CONVERSION FACTOR (N/V)	CORRELATION
RV ₁	200	57.97	.99999
R ₂₂	140	40.613	.99986
R ₃₂	140	39.65	.99998
HV ₁	140	40.44	1.00000
H ₂₃	140	40.693	.99927
H ₅₃	140	40.23	.99991
V ₂₅	200	51.14	.9969999
V ₃₅	200	58.20	1.00000
V ₃₆	240	121.51	.99999

For each load cell, two loads were applied to the transducer and the shim was pulled 1 inch to 2 inches in the 3 seconds of scanning.

The shim surface was finished so that its surface roughness was in the neighborhood of that of the load cells. Three of the top load cell support surfaces on segment 2 were found to have a surface roughness of 0.63 μm , 0.46 μm and 0.48 μm . The shim was roughened with sandpaper and random measurements of its surface gave surface roughness measurements of 0.27, 0.30, 0.36, 0.65, 1.82 and 3.04 which indicated that the surface roughness was the same order of magnitude as that of the load cell support surfaces.

The load cell output was recorded digitally using an HP 9816 computer and processed so that plots of the load could be obtained.

Table 4.3 gives the results of the tests. The standard deviation of the measured load does not vary greatly among the load cells. This indicates that all of the load cells have approximately the same response to friction and testing of more load cells is probably redundant.

There does not seem to be a correlation between the applied load and the standard deviation. The mean of the standard deviations is 0.14 N and the median is 0.11 N. A value of 0.14 N for deviation of measured load under friction will be used in all further load calculations where needed.

It should be noted that using thin shims for this type of test was dictated by economic rather than technical considerations. The gouging effect of a hard ball on a soft shim will probably have an effect on the result if internal sliding and external rolling does not occur. Further investigation will be useful, and the results of this test should only be used for guidance.

TABLE 4.3

FRICTION CALIBRATION OF LOAD CELLS

TRANSDUCER #	MEASURED LOADS			STANDARD DEVIATION (N)
	MEAN (N)	MINIMUM (N)	MAXIMUM (N)	
111	46.60	47.72	47.81	.11
	46.95	46.62	47.81	.28
109	19.07	18.99	19.14	.10
	39.37	39.22	39.53	.10
103	22.13	21.98	22.27	.33
	46.67	46.56	46.79	.11
104	21.95	21.89	21.98	.05
	46.01	45.85	46.34	.14
106	17.91	17.84	17.98	.04
	37.35	37.16	37.53	.13

4.3 External Load Calibration Rig

4.3.1 Calibration Rig Design

The function of the calibration rig is to apply a known load, at a known position on the hull's surface for the purpose of segment calibration. It must be able to operate with the model in water as well as in air. To accomplish this task, an adjustable articulated arm was designed with a triaxial force transducer mounted on the outer end. To complicate this task, the load must be applied from the model to eliminate problems associated with buoyancy effects on the segment. The load must be able to be applied with the model free floating. Figure 4.4 shows a schematic diagram of the calibration rig.

Mounted along the ship's centreline, just slightly above deck level, is a linear bearing rod. Attached to this rod is a linear bearing and turntable, which is infinitely adjustable along the ship's "x" axis between approximately stations 6.5 and 10.25 (station 10 being the forward perpendicular). This range permits the calibration of all three segments. The distance along the centreline from the turntable to midships will be called r_1 .

In a plane parallel to the waterline, attached to the turntable, is the deck adjustable arm. The deck adjustable arm can be positioned at any angle relative to the centreline, and can have any length. The distance along the deck adjustable arm from the turntable to the hinge point will be called r_2 . The angle is adjusted with the turntable, and the length is adjusted with the aid of a rack and pinion assembly located at the hinge point. This angle is called α_c .

The side adjustable arm is mounted to the deck adjustable arm at the hinge point again with the aid of a rack and pinion.

The triaxial force transducer is mounted at the end of the side adjustable arm. A round head screw is mounted on the triaxial transducer at the point where it contacts the ship hull. By using a round head screw a slightly off-normal force can be applied to the hull. The distance along the side adjustable arm from the hinge point to the round head screw will be called r_3 . The side adjustable arm, together with the deck adjustable arm, form a scissor arrangement in the plane of the two arms. The angle between arms r_2 and r_3 is called θ .

Therefore by properly setting the arm lengths r_1 , r_2 , and r_3 and the turntable angle α_c and by applying a force F on the outer end of the scissors and measuring the load with the triaxial transducers, a known load can be applied to a known point. In Figure 4.5 the calibration rig is shown applying a load to a point on segment 1.

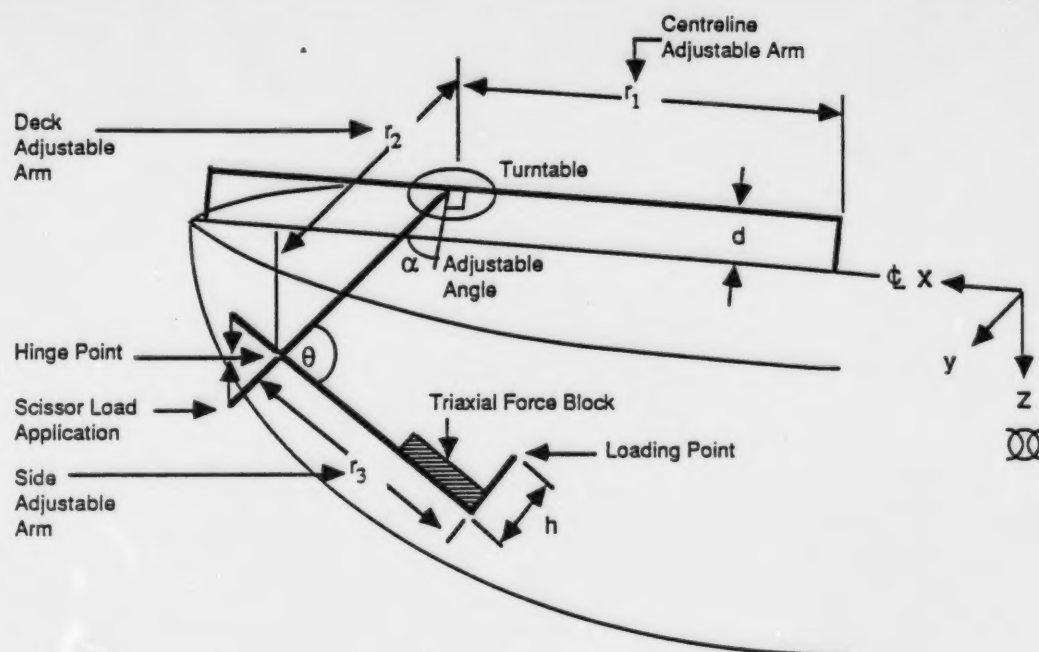


Figure 4.4 CALIBRATION RIG

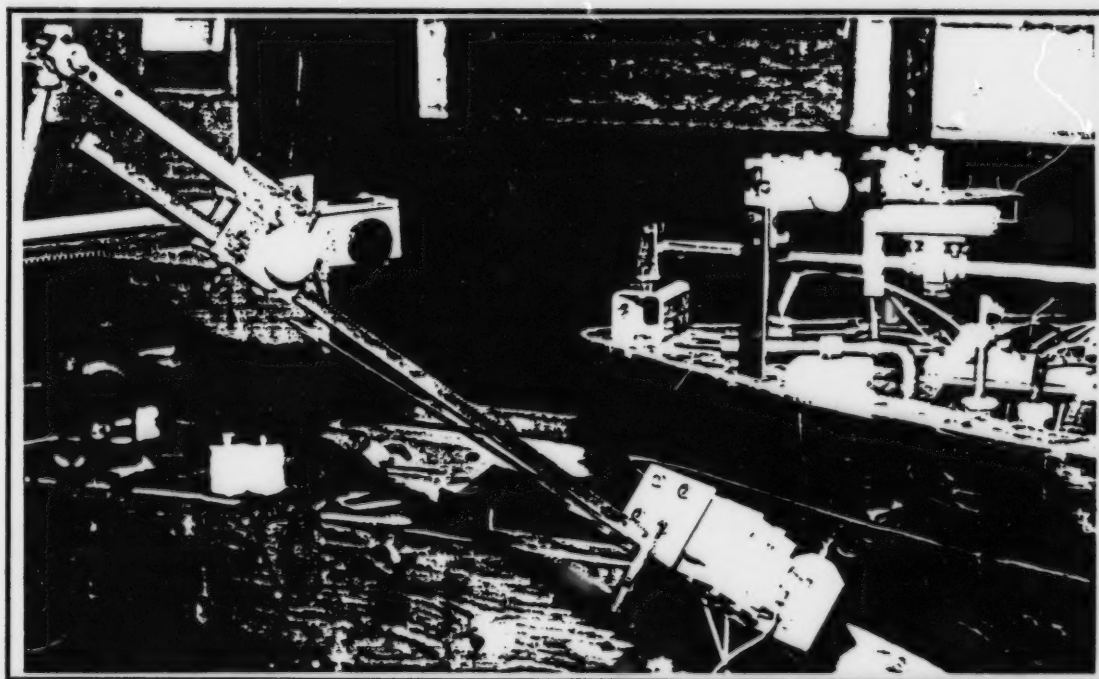


Fig 4.5 THE CALIBRATION RIG APPLYING A LOAD TO SEG. 1

From knowledge of x , y , z , α and β on the surface of the model hull the settings of the calibration rig, r_1 , r_2 , r_3 and α for application of a normal load and frictional load can be determined from the geometry of the model and calibration rig. Firstly, however, y , α and β must be found from the x and z coordinates. It is possible to find y , α and β from the lines plan. However, rather than use the lines plan to find y , α and β for each calibration point, the "Hull Form Interpolation" subroutine discussed in Section 3 was used. This subroutine fits cubic splines to stored offsets to determine y , α and β .

The solution of the calibration rig parameters from the hull parameters is outlined in Appendix B. The equations were implemented in a computer subroutine labelled the "calibration rig set-up subroutine". This subroutine was used in conjunction with the hull interpolation subroutine so that the calibration rig parameters could be found in one step.

4.3.2 Resolving Calibration Rig Forces

The calibration rig can be set up so that it is applying a load at a known point on the hull at a known angle α and θ . The only problem remaining is to measure the applied load. Theoretically only one transducer oriented in the direction in which the calibration rig probe acts is needed. Practically it was desired to verify that only a load in the direction of the calibration rig probe was applied so a triaxial force transducer was mounted between the calibration rig and the probe. It was then necessary to resolve the forces measured by the triaxial block into the forces in the ship coordinate system. A discussion of the equations used to resolve the forces is available in Appendix C.

4.3.3 Calibration Rig Accuracy

The calibration rig itself is a possible source of two errors in the calibration process. First the errors in measuring the lengths of the three arms of the rig, and the angle between the arm, r_2 , and the longitudinal axis of the ship create a position error at the point of load application. This results in a force being applied to the hull at a slightly different position and direction than planned. The position error was estimated to be $\pm 0.5\text{mm}$ in either the x or z coordinates. The second source of error is in the calibration rig angles α and θ . The magnitude of the error can be estimated theoretically by finding the change of the principal forces for a change in the calibration rig angles. α is the waterplane angle of the model and when the calibration rig is set normal to the model hull during the calibrations it equals α , the angle between the calibration rig arms r_1 and r_2 as shown in Figure 4.6. When the calibration rig is normal to the hull θ equals the normal flare angle from the horizontal of the plane tangent to the model hull. For the calibration rig it is the angle between arms r_2 and r_3 as shown in Figure 4.6.

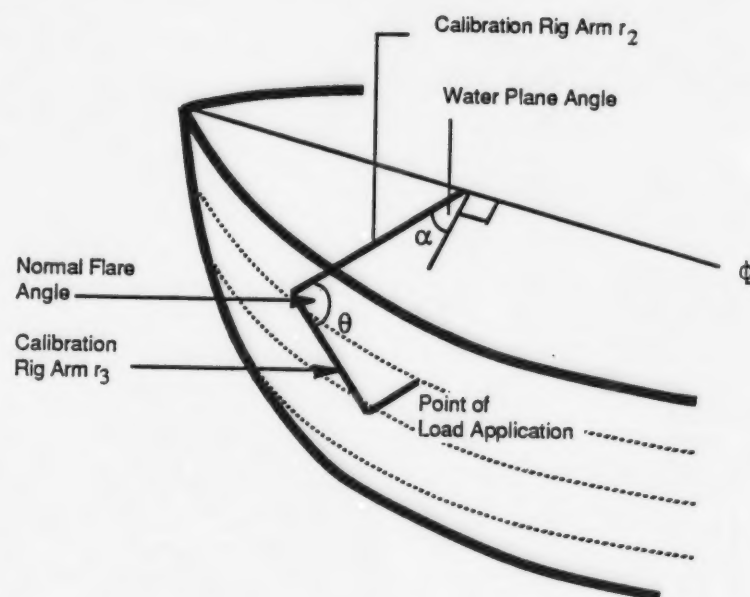


Figure 4.6 Definition of water plane angle α , and normal flare angle θ of the calibration rig.

The theoretical analysis has been done for normal loads only, thus the effect of error in α or θ on the friction force has not been evaluated. The change has been calculated in percentage form for the change in force when the angle is changed by two degrees. It was found that the F_x (force in the x direction) was particularly sensitive to values of α less than 20° as shown in Figure 4.7. On segment 3, α is usually less than 20° so higher error in the prediction of F_x can be expected, if α is in error.

As shown in Figure 4.8 F_y and F_z (the forces in the y and z direction) are sensitive to changes when θ is small. For values of θ between 36 and 50° errors in F_y and F_z are 2% to 3% if θ is in error by 2° . These values of θ are found on segments 2 and 3. F_y and F_z on segment 3 will be insensitive to errors in θ : the forces will change 1% or less if the angle changes by 2° .

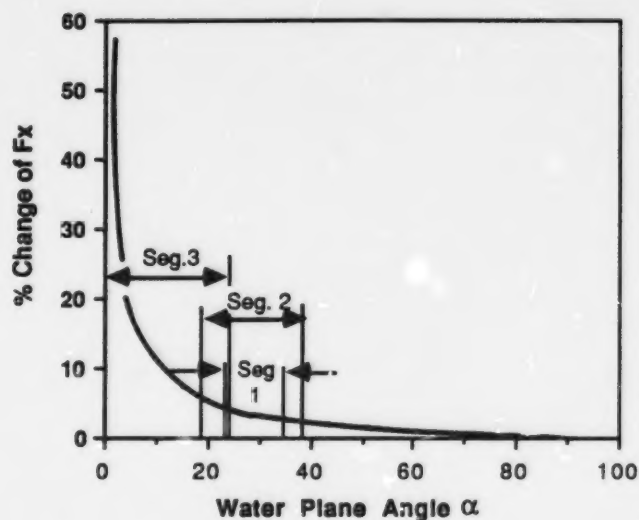


Figure 4.7 ABSOLUTE PERCENT CHANGE in F_x FOR A 2 DEGREE ERROR IN WATER PLANE ANGLE
 Note: for a normal force

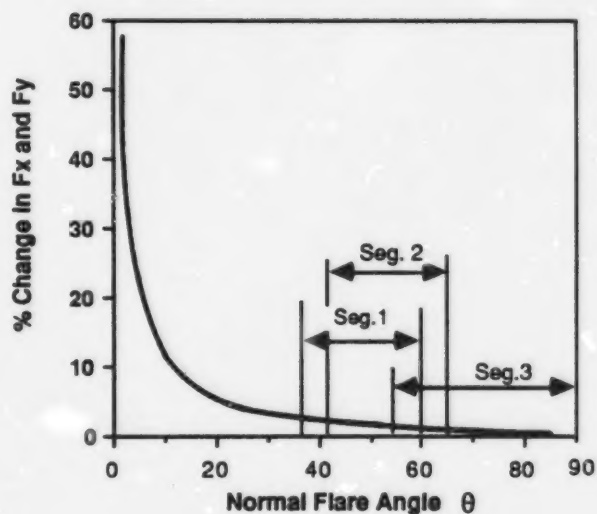


Figure 4.8 ABSOLUTE PERCENT CHANGE in F_y and F_z FOR A 2 DEGREE ERROR IN THE NORMAL FLARE ANGLE
 Note: for a normal force

4.4 Segment Calibration Procedure

4.4.1 External Calibration Procedure

To fully test the transducers and the segment response to loads, known loads were applied at known points. The calibration rig described in section 4 was used to apply the loads. To thoroughly calibrate the segment, 10-15 points on each segment were chosen for application of the calibration loads. These points will hereafter be referred to by number. The location of each point on Segments 1, 2 and 3 and their reference numbers are shown in Figures 4.9, 4.10 and 4.11. The x and z coordinates and the y, α and β values at the points as found the hull interpolation program are given in Table 4.4 for Segment 1, Table 4.6 for Segment 2 and Table 4.8 for Segment 3. The calibration rig parameters for the points as determined by the calibration set-up algorithm are given in Tables 4.5, 4.7, and 4.9 for Segment 1, 2 and 3 respectively.

The response of the segments was calibrated initially with the model supported on a cradle in the workshop. This permitted the calibrations to be carried out easily while visually checking the position of the applied force. These calibrations have been labelled the in-air calibrations. During this calibration test the vertical tension ring preloads were increased to account for the buoyancy which would normally act during the in-water calibration and testing.

When the in-air calibrations were completed the model was placed in the basin, ballasted and attached to the heave staff, and a second calibration test set was carried out. The preloads were relaxed and reset to the correct amounts except as discussed under calibration results. The second calibration test has been labelled the in-water calibration.

The same procedure was carried out during the in-water calibration as during the in-air calibration with the following exceptions.

- 1) No observation of the point of load application could be made, due to submergence.
- 2) The basin may not have presented a completely still environment to the segment. Reflected waves caused by model movement during the setting of the calibration rig may not have completely died out.
- 3) Fewer points were calibrated in-water: 4 on Segment 2 and 6 on Segment 3.

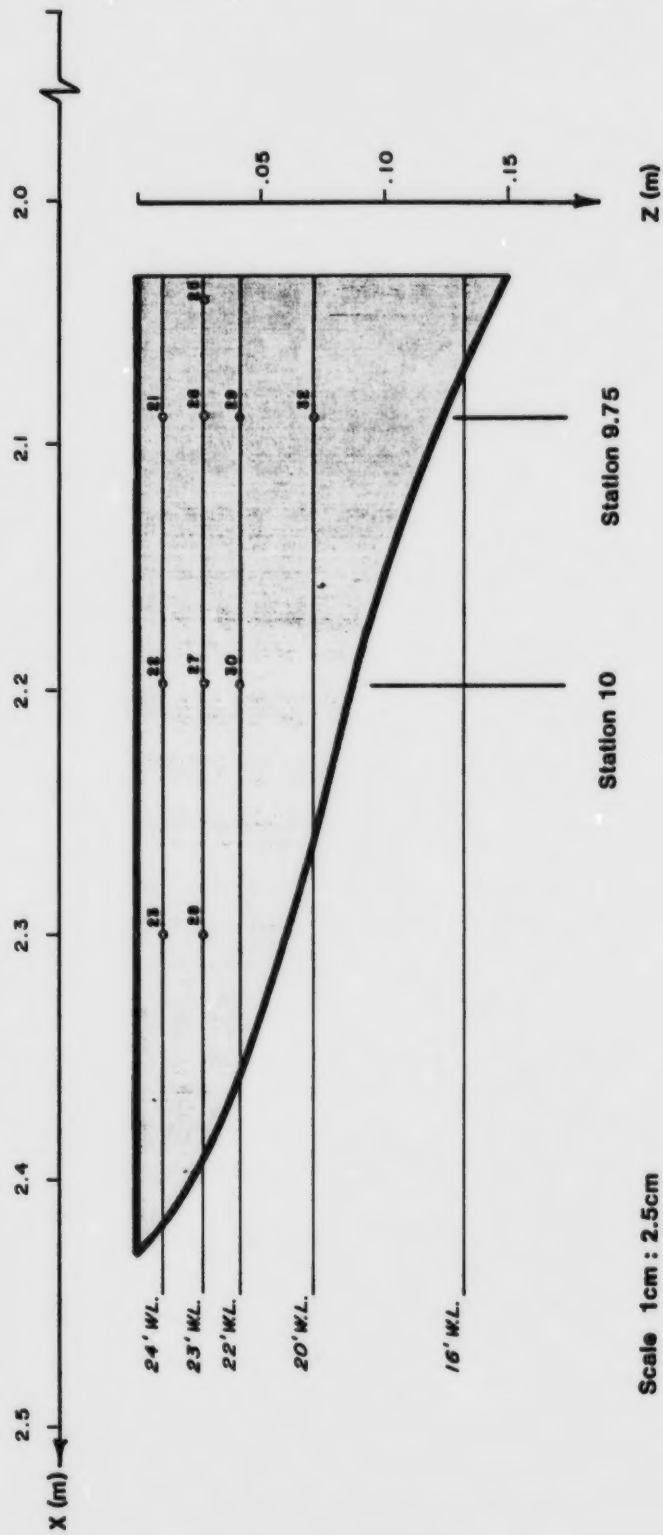


Figure 4.9 SEGMENT 1 CALIBRATION POINTS

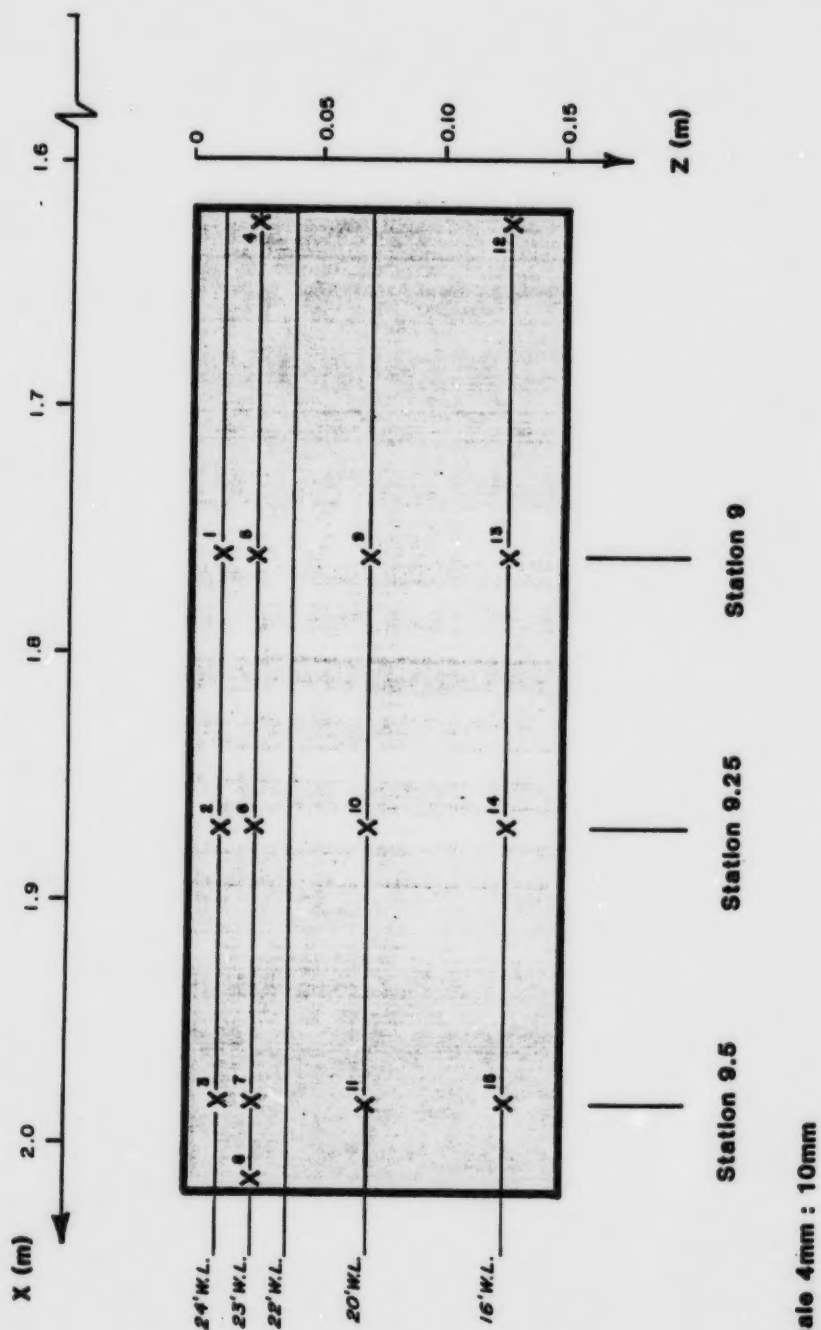


Figure 4.10 SEGMENT 2 CALIBRATION POINTS



Figure 4.11 SEGMENT 3 CALIBRATION POINTS

TABLE 4.4

SEGMENT 1: HULL PARAMETERS AT THE CALIBRATION POINTS

(NUMBERS 21-34)

CALIBRATION POINT NUMBER	z WATERLINE	z (m)	x STATION	x (m)	y (m)	α deg	β deg
21	24'	.011	9.75	2.083	.162	29.2	45.8
22			10	2.198	.102	29.1	48.2
23			10.23	2.298	.047	26.9	51.6
24			-	2.35	.023	23.1	33.0 ²
25	23'	.027	-	2.040	.174	29.8	48.1 ²
26			9.75	2.088	.146	29.7	51.1
27			10	2.198	.083	30.8	53.4
28			10.23	2.298	.027	24.3	50.9
29	22'	.042	9.75	2.088	.126	30.9	53.7
30			10	2.198	.061	28.8	56.7
31			10.23	2.298	.013	22.3	37.0 ³
32	20'	.072	9.75	2.088	.085	34.0	52.5
33			10	2.198	.012	33.1	59.7
34	16'	.133	-	2.040	.027	39.4	60.01 ¹

1 - values found from measurement of segment 1

2 - β approximated by interpolation

3 - values found from lines plan

TABLE 4.5

CALIBRATION RIG PARAMETERS FOR SEGMENT 1 CALIBRATION POINTS

Note: For the calibration rig normal to the segment

CALIBR. POINT	z WATERLINE	z (m)	x STATION	x (m)	r ₁ (m)	r ₂ (m)	r ₃ (m)	α deg	θ deg
21	24'	.011	9.75	2.088	1.998	.537	.476	29.2	48.1
22			10	2.198	2.141	.507	.505	29.1	45.7
23			10.23	2.298	2.274	.497	.548	26.9	41.6
24			-	2.350	2.340	.279	.410	23.1	59.1
25	23'	.027	-	2.040	1.940	.602	.524	29.8	46.0
26			9.75	2.088	2.005	.609	.555	29.7	42.9
27			10	2.198	2.149	.570	.581	30.8	40.9
28			10.23	2.298	2.286	.490	.570	24.3	41.7
29	22'	.042	9.75	2.088	2.014	.644	.609	30.6	40.5
30			10	2.198	2.169	.644	.675	25.6	36.1
31 ¹			10.23	2.298	2.292	.224	.410	25.6	66.7
32	20'	.072	9.75	2.088	2.031	.595	.624	34.0	42.6
33 ¹			10	2.198	2.190	.658	.749	33.1	34.9
34 ¹	16'	.133	-	2.040	2.018	.719	.815	39.5	36.8

1 - Position not used during calibrations because of difficulty in reaching it with the calibration rig.

TABLE 4.6

SEGMENT 2: HULL PARAMETERS AT THE CALIBRATION POINTS

CALIBRATION POINT NUMBER	z WATERLINE	z (m)	x STATION	x (m)	y (m)	α deg	β deg
1	24'	.0114	9	1.759	.325	13.6	31.7
2			9.25	1.869	.294	25.2	36.8
3			9.5	1.979	.223	33.3	41.4
4	23'	.0267	-	1.625	.366	18.8	27.2*
5			9	1.759	.315	22.9	33.2
6			9.25	1.869	.265	25.9	38.7
7			9.5	1.979	.208	28.9	44.4
8			-	2.015	.189	29.7	46.4*
9	20'	.072	9	1.759	.282	25.6	39.2
10			9.25	1.869	.225	29.4	44.0
11			9.5	1.979	.158	33.0	50.5
12	16'	.133	-	1.625	.298	24.5	39.8*
13			9	1.759	.223	30.6	48.9
14			9.25	1.869	.159	34.8	50.5
15			9.5	1.979	.077	37.9	54.6

* β found from straight line interpolation of neighboring stations.

TABLE 4.7

CALIBRATION RIG PARAMETERS FOR SEGMENT 2 CALIBRATION POINTS

CALIBR. POINT	z WATERLINE	z (m)	x STATION	x (m)	r ₁ (m)	r ₂ (m)	r ₃ (m)	α deg	θ deg
1	24'	0.11	9.0	1.759	1.681	.560	.351	23	60.4
2			9.25	1.869	1.730	.574	.367	24.7	55.8
3			9.5	1.979	1.833	.534	.379	27.8	52.0
4	23'	.027	-	1.625	1.500	.586	.347	18.8	64.0
5			9.0	1.759	1.626	.577	.370	22.9	58.9
6			9.25	1.869	1.740	.568	.395	25.9	54.2
7			9.5	1.979	1.864	.554	.426	28.9	49.4
8	20'	.072	0	2.015	1.908	.553	.441	29.7	47.4
9			9.0	1.759	1.624	.623	.454	25.6	53.7
10			9.25	1.869	1.742	.608	.482	29.4	49.9
11	16'	.113	9.5	1.979	1.876	.604	.531	33.0	44.5
12			-	1.625	1.489	.693	.536	24.5	52.8
13			9.0	1.759	1.624	.729	.608	30.6	45.4
14			9.25	1.869	1.760	.659	.611	34.8	45.1
15	.		9.5	1.979	1.920	.613	.649	37.9	42.0

TABLE 4.8

SEGMENT 3: HULL PARAMETERS AT THE CALIBRATION POINTS

(NUMBERS 41-55)

CALIBRATION POINT NUMBER	z WATERLINE	z (m)	x STATION	x (m)	y (m)	α deg	β deg	
41	24'	.0114	-	.89	.480	0.6	7.4	2
42			8	1.319	.444	8.9	12.8	1
43			-	1.613	.378	17.2	24.8	
44	23'	.0267	-	.89	.478	0.8	7.3	2
45			8	1.319	.440	9.2	14.0	1
46			-	1.613	.370	18.4	26.6	
47	22'	.042	-	.89	.476	0.7	7.4	2
48			8	1.319	.436	9.8	15.3	1
49			-	1.613	.362	19.4	28.4	
50	20'	.072	-	.89	.472	0.8	8.1	2
51			8	1.319	.427	11.1	18.1	1
52			-	1.613	.345	20.8	31.9	
53	16'	.133	-	.89	.461	1.2	12.32	1
54			8	1.319	.403	13.9	24.5	1
55			-	1.613	.303	24.0	38.4	

1 - β found from waterline interpolation2 - β approximated by those at $x = .879$

TABLE 4.9

CALIBRATION RIG PARAMETERS FOR SEGMENT 3 CALIBRATION POINTS

Note: Parameters are for the calibration rig normal to the hull calibration

CALIBR. POINT	z WATERLINE	z (m)	x STATION	x (m)	r ₁ (m)	r ₂ (m)	r ₃ (m)	α deg	θ deg
41	24'	.011	.89	-	.885	.575	.335	0.6	82.6
42			1.319	8	1.249	.576	.345	8.9	77.3
43			1.613	-	1.496	.596	.378	17.2	66.2
44	23'	.027	.89	-	.883	.574	.350	0.8	82.7
45			1.319	8	1.248	.583	.364	9.2	76.1
46			1.613	-	1.490	.610	.402	18.4	64.6
47	22'	.042	.89	-	.884	.575	.366	0.7	82.6
48			1.319	8	1.243	.592	.383	9.8	74.9
49			1.613	-	1.487	.624	.426	19.1	62.9
50	20'	.072	.89	-	.884	.579	.397	0.8	81.9
51			1.319	8	1.235	.613	.422	11.1	72.2
52			1.613	-	1.482	.654	.477	20.8	59.8
53	16'	.113	.89	-	.880	.612	.469	1.2	77.7
54			1.319	8	1.219	.670	.512	13.9	66.1
55			1.613	-	1.478	.720	.589	24.0	54.1

Loads between 20 and 40N were applied with the average load applied being 30N. 75N is the design load of the segments. However these loads are closer to the loads seen during ice testing. To apply the calibration load, first a load of 15 to 20N was applied to insure that the calibration rig would stay at the correct position on the hull. A zero reading was taken and then the load increased to about 50N and a final reading taken. These forces were intended to act normal to the hull at each calibration point, but due to small deflections of the calibration apparatus some forces were induced in the plane of tangent to the hull.

The calibration procedure was such that at each calibration location two to six load steps were applied to the segment following the zero reading. The outputs from the transducers both in the calibration apparatus and in the segment were recorded by the microcomputer and stored on disk. Signal conditioning settings were the same as those used during testing, and the same cabling and channel assignments were used.

In addition to the calibration performed on all three segments after the final segment modifications, preliminary calibrations were performed on Segment 2. These took place before the final modifications to Segment 2. Their purpose was to verify that the support system concept utilized on Segment 2 was operational before modifications to Segments 1 and 3 were made. The same calibration procedure was followed except that an initial load was not applied and therefore the net applied loads were much larger, on average 70-75N.

For each calibration test the results were printed in a standard format as shown in Figure 4.12, which gave the following information:

- 1) The measurement resulting on each segment transducer from the applied force.
- 2) The measurements recorded by the calibration rig transducers which are labelled NOR, T_1 and T_y which refer to the three load components in the calibration rig coordinates as discussed in Appendix C.
- 3) The applied force in the x, y and z directions (ship coordinates).
- 4) The measured force in the x, y and z directions (ship coordinates).
- 5) The % difference in the x, y and z forces which has been defined as $(F_m - F_a)/F_m$ where F_m is the measured force and F_a is the applied force.
- 6) The x and z coordinates of the applied force as determined by the calibration point position as preset and applied.

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 17 SEGMENT NUMBER 3 FILE NAME POS_46
 CALIBRATION POSITION 46

TRANSDUCER	READING (N)
R-31	2.65
R-32	.39
H-31	18.12
H-32	-.35
H-33	1.18
V-31	-5.08
V-32	22.49
V-33	.70
V-34	-1.06
V-35	1.42
V-36	.59
T'V	9.82
T'L	-2.74
NOR	26.28

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	3.56	3.04	-15.	-.5
	Y	19.39	18.95	-2.	-.4
	Z	20.15	19.07	-5.	-1.1

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -6.70 X PLANE
 C2= 13.41 Y PLANE
 C3= -12.22 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.613	1.607	-.006 m
Z=	.027	.021	-.006 m
WATERPLANE ANGLE	18.	18.	-1. DEG
FLARE ANGLE	27.	26.	-1. DEG
TOTAL FORCE	28.188	27.049	-4.0 %
NORMAL FORCE	26.279	25.187	-4.2 %
FRICTION FACTOR	.388	.392	
FRICTION FORCE	10.198	9.862	-3.3 %
FRICTION DIRECTION FROM THE HORIZONTAL	106.	107.	1. DEG

Figure 4.12 CALIBRATION TEST SHEET

- 7) The x and z coordinates of the measured force which have been determined by the position calculation algorithm.
- 8) The error in x and z in millimeters which has been defined as the applied coordinate subtracted from the measured coordinate. A positive error in the case of x means the measured force was forward of the applied force and in the case of z means the measured force is above the applied force.
- 9) The hull angle at the calibration point.
- 10) The measured hull angles as determined by the position algorithm.
- 11) The error in the hull angles; again measured minus applied.
- 12) The total applied force and its normal and friction components as determined by the calibration rig transducers and the calibration point.
- 13) The total measured force and its normal and friction components whose ratio are determined by the measured position.
- 14) The percentage error in the total, normal and applied forces which is defined as $(F_m - F_a)/F_a \times 100$ where F_m is the measured force and F_a is the applied force.
- 15) The applied friction direction.
- 16) The measured friction direction which is calculated from the friction indices as described in Chapter 3.

The calibration sheets for all the calibrations performed in-air and in-water are presented in Appendix D.

4.4.2 Internal Calibration Procedures

In order to determine the response of the segments to loads applied along the x, y and z axes, (pure longitudinal, horizontal and vertical loads) a calibration was carried out using the respective tension links to apply the load as shown on Figure 4.13. The response of the compression load cells could then be observed. In this calibration, ideally only those load cells recording loads in the direction of the applied load should record significant loading.

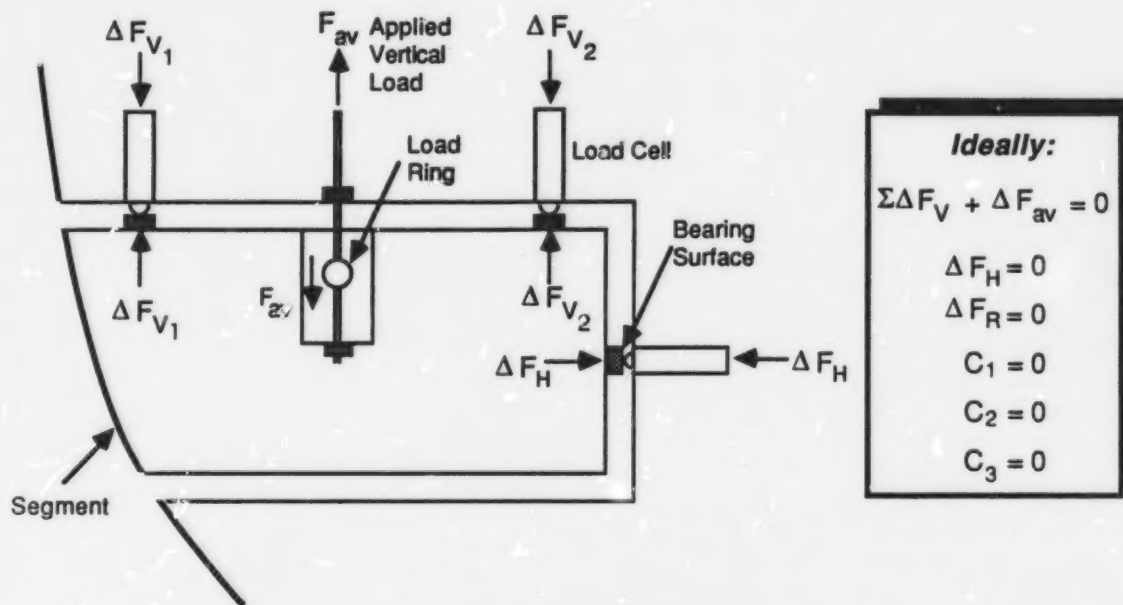


Figure 4.13

MECHANICS OF AN INTERNAL VERTICAL CALIBRATION

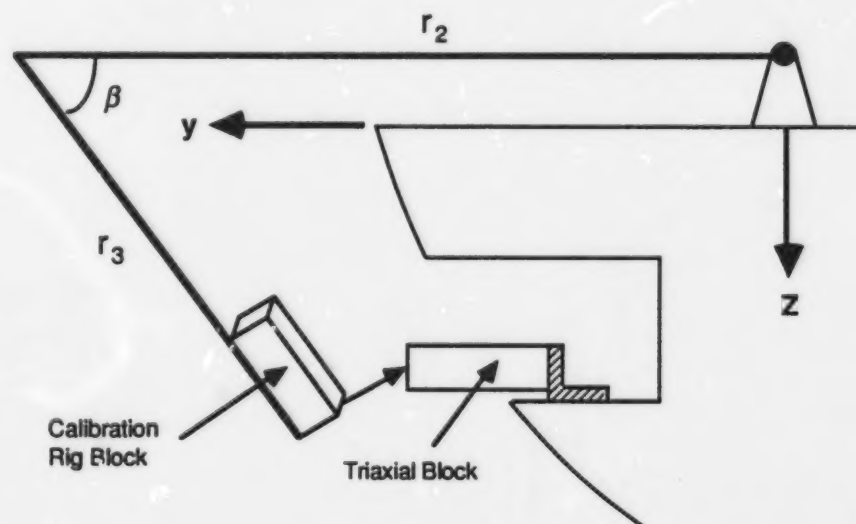


Figure 4.14

ARRANGEMENT OF CALIBRATION RIG VERIFICATION TEST

(Transverse Section)

The procedure for carrying out this calibration was to leave the tension links normal to the direction of force to be applied at this correct preload, and to increase and decrease the preload on the remaining tension link. Segment 2 was only calibrated in-water but Segments 1 and 3 were calibrated in this manner both in air and in water.

Segment 1 formed a special case because the tension links do not lie along normal axes so it was not possible to apply forces along one axis only. Each of the tension link measurements was separated into axial components for this calibration.

The results of the tensioning calibrations for each segment are presented in Chapter 5.

4.4.3 Segment Nonlinearities

Segment nonlinearities exhibited by segments 1, 2 and 3 were determined by sequentially increasing and then decreasing the load using the calibration rig. Nonlinearity tests were performed at one location on segment 2 and two locations on segments 1 and 3.

4.4.4 Calibration Rig Verification Tests

It had been noted earlier that The calibration rig is a possible source of error in the calibration process. An experiment was carried out to verify that the deflections in the calibration rig arms were causing errors in the calculation of the applied load. Also the experiment was intended to see if the errors were dependent on the waterplane angle (α) and the normal flare angle (θ). Essentially this was a calibration of the calibration rig. Segment 3 was removed from the model and a triaxial force block was fixed inside the model so that the end to be loaded extended outside of the hull surface as shown in Figure 4.14. The calibration rig could then contact the loading point on the block at various waterplane and normal flare angle values, α and θ values. Since the loading point of the calibration rig was a roundhead screw, the point at which the screw was to contact the triaxial block was slightly countersunk so that the calibration rig would have a normal surface to act on and would not move during testing.

Four tests were performed. Theta, the normal flare angle was held constant at 70° and then 60° while α was varied from 0 to 30° . A θ of 70° corresponds to normal flare angles on Segment 3 and $\theta = 60^\circ$ corresponds to normal flare angles on segment 2. Unfortunately in order to achieve values of θ which would correspond to segment 1 the calibration rig arms r_2 and r_3 would have to be unreasonably long. Individual test results are in Appendix D.4.

5. CALIBRATION RESULTS

5.1 Overview

The calibration test results will be presented in the following sections. The presentation and discussion of calibration results for segments 1, 2 and 3 is followed by the calibration rig verification test results and finally an analysis and assessment of the accuracy of the measuring system. The primary objective of this analysis was to establish the accuracy of measurement of the external ice load; its magnitude, position, and components so that when performing measurements during icebreaking the level of confidence in the measurements will be known and established. Hence, interpretation of the results could be made with due confidence.

5.2 Segment 1 - Calibration Results

5.2.1 External Calibrations

The procedure outlined in Chapter 4 was used to apply known loads to segment 1 using the calibration rig. The result sheets from the calibration tests are given in Appendix D.1.

Because transducers RV_1 and HV_1 both act in oblique planes as described in Chapter 2 their measurements have been resolved into their components in the ship model coordinate system. On the calibration sheets $RV-1$ indicates the z component or RV and $RV-x$ the x component while $HV-1$ indicates the z component of HV_1 and $HV-y$ is the y component of HV_1 . The total output of each transducer would be the square root of the sum of the squares of the two components. Table 5.1 is a summary of the results from the segment 1 calibrations. Maximum, minimum, mean and standard deviation of each column are given at the bottom of the Table. The ratio of applied force to measured force and the error for F_x , F_y , F_z , the normal force, the friction force as well as the error in mm for the x and z coordinates are presented in the Table 5.1. It should be noted that further analysis of the errors suggests a Gaussian distribution, hence normal statistics may be used. This analysis is presented later in this chapter.

Consider segment 1, it is observed that in the y and z directions the largest ratios are about 1.27 of the applied load but only in two cases is the absolute error larger than 5N. A mean ratio is shown indicating a consistent error of about 4% in the y direction and 14% in the z direction. The segment is consistently over predicting the applied load in the y and z directions at 1.04 and 1.13 of the applied load, respectively. The standard deviation indicates the random error, this is 0.08 and 0.12 of the applied load for F_y and F_z respectively, but this represents forces of less than 2N. The force in the x direction shows ratios of up to 1.80 of the applied load but this results from an error of only 2.0N. The measured force in the x direction has an average ratio of 1.28 to the applied force and a standard deviation of .45 or 2.6N.

Table 5.1 Summary of Uncorrected Segment 1 Calibrations

Calibration Position	Air or Water (A/W)	Total Applied Force Newtons	Ratio of Fx	Error in Fx Newtons	Ratio of Fy	Error in Fy Newtons	Ratio of Fz	Error in Fz Newtons
21	A	17.1	1.80	2.0	1.08	0.7	1.17	2.5
22	A	26.4	1.69	3.5	1.02	0.3	1.22	4.5
23	A	36.3	1.32	2.1	1.07	1.0	1.23	6.0
25	A	39.1	1.48	3.5	0.99	-0.1	1.17	5.6
25	W	28.6	0.91	-0.8	0.83	-3.0	1.20	4.2
26	A	33.6	1.51	4.1	1.11	1.9	1.26	7.1
26	W	26.2	1.39	3.4	1.13	1.8	1.27	5.6
27	A	40.0	1.32	7.8	0.98	-0.4	1.10	3.6
27	W	30.5	1.15	1.4	1.05	0.7	1.16	3.9
28	A	31.8	0.96	-0.2	1.10	1.5	1.01	0.4
29	A	38.6	1.77	3.6	0.99	-0.2	1.10	3.5
29	W	22.6	1.24	1.9	1.07	0.8	1.12	2.1
30	A	30.4	1.33	2.0	1.08	1.0	1.03	0.8
32	A	33.0	0.03	-3.4	1.00	0.0	0.81	-5.9
Minimum		17.1	0.03	-3.4	0.83	-3.0	0.81	-5.9
Maximum		40.0	1.80	7.8	1.13	1.9	1.27	7.1
Mean		31.0	1.28	2.2	1.04	0.4	1.13	3.1
Stand. Dev.		6.5	0.45	2.6	0.08	1.2	0.12	3.2

Calibration Position	Air or Water (A/W)	Ratio of Normal Force	Error in Normal Force Newtons	Ratio of Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm	Error in Friction Dir. deg
21	A	1.15	2.6	1.22	1.7	1	0	-15
22	A	1.17	4.5	1.04	0.2	-26	3	
23	A	1.17	5.2	1.64	3.5	-41	2	
25	A	1.14	5.4	1.10	1.0	9	6	-17
25	W	1.04	0.9	2.30	3.2	16	11	
26	A	1.21	6.9	0.98	-0.1	16	6	
26	W	1.24	6.4	1.38	0.9	5	13	
27	A	1.13	5	0.91	-1.0	-7	2	-38
27	W	1.12	3.5	1.54	1.0	-12	4	
28	A	1.04	1.1	0.89	-0.6	-10	-5	
29	A	1.09	3.1	1.01	0.1	1	-1	-17
29	W	1.11	2.5	1.66	0.9	6	2	
30	A	1.05	1.3	0.97	-0.2	-12	0	
32	A	0.82	-5.5	0.86	1.9	-2	-18	
Minimum		0.82	-5.5	0.86	3.8	-41	-18	-38
Maximum		1.24	6.9	2.30	-1.0	16	11	-15
Mean		1.11	3.1	1.25	0.9	-4	2	-17
Stand. Dev.		0.10	3.1	0.41	1.3	16	7	

The majority of errors in the position of the force are low. The x coordinate is offset on the average by 4 mm and has a standard deviation of 16mm while the z coordinate is offset by 2mm and has a standard deviation of 7mm - which is very low.

The normal force is predicted as 1.11 of the applied normal force on average with a standard deviation of 0.10. The worst predicting is 1.24 of the applied normal force. The absolute size of this error is at worst 6.9N, standard deviation 3.1N with a 3.1N offset. A standard deviation of 3N is quite low. In English units this is approximately 11 ounces. The result is that in the majority of the cases the measured normal force was between 1.01 or 1.21 of the applied force or that the error was between 1% and 21% of the applied load. For the normal applied loads, 17N to 40N, this becomes an error of .02N to 8N.

The friction force appears to have an average error of 0.9 N with a standard deviation of 1.3 N. The largest error is less than 4 N. The error rather than the ratio is a better description of the success of Segment 1 in predicting the friction forces. Since these forces are quite low - generally less than 10 N, a high ratio, for example 1.66, is actually only an error of 0.9 N which is a negligible amount.

5.2.2 Segment 1 Corrected Calibration Results

As can be seen in Table 5.1 Segment 1 overpredicts forces in the x direction and in the z direction. Because of its position at the bow of the model it has waterplane angles as large as 39° and flare angles up to 60°. This results in hull normals which have a much larger vertical component than the hull normals on segments 2 and 3. So the vertical component of the normal force has a much larger influence on the normal force than it does on the other two segments. For this reason, it was decided to apply a correction by multiplying the measured vertical force by 0.88. A correction factor was not applied to F_x for several reasons. First, although the percentage error is highest in the x direction, in absolute terms it is almost 1 N lower than the error in the z direction. Second, because F_x is the smallest component of the normal force a correction would not significantly improve the overall segment response. Third, because of the large standard deviation it was felt that this was mostly a random error due to calibration rig error, inaccurate hull lines, and segment error. The results, after applying a vertical correction factor are shown in Table 5.2. By reducing the ratio of measured vertical forces to 1.00 the ratio of normal forces has improved from 1.11 to 1.03. The vertical correction factor has been used in the reduction of the ice test data.

Table 5.2 Summary of Corrected Segment 1 Calibrations

Calibration Position	Air or Water (A/W)	Total Applied Force Newtons	Ratio of Fx	Error in Fx Newtons	Ratio of Fy	Error in Fy Newtons	Ratio of Fz	Error in Fz Newtons
21	A	17.1	1.80	2.0	1.08	0.7	1.01	0.0
22	A	26.4	1.69	3.5	1.02	0.3	1.05	1.1
23	A	36.3	1.32	2.1	1.07	1.0	1.05	1.3
25	A	39.1	1.48	3.5	0.99	-0.1	1.01	0.2
25	W	28.6	0.91	-0.8	0.83	-3.0	1.03	0.7
26	A	33.6	1.51	4.1	1.11	1.9	1.07	1.8
26	W	26.2	1.39	3.4	1.13	1.8	1.09	1.9
27	A	40.0	1.32	7.8	0.98	-0.4	0.95	-1.8
27	W	30.5	1.15	1.4	1.05	0.7	0.99	-0.3
28	A	31.8	0.96	-0.2	1.10	1.5	0.87	-3.5
29	A	38.6	1.77	3.6	0.99	-0.2	0.94	-2.0
29	W	22.6	1.24	1.9	1.07	0.8	0.96	-0.7
30	A	30.4	1.33	2.0	1.08	1.0	0.90	-2.8
32	A	33.0	0.03	-3.4	1.00	0.0	0.70	-9.4
Minimum		17.1	0.03	-0.8	0.83	-3.0	0.87	-3.5
Maximum		40.0	1.80	7.8	1.13	1.9	1.09	1.9
Mean		31.0	1.28	2.2	1.04	0.4	0.97	-1.0
Stand. Dev.		6.5	0.45	2.6	0.08	1.2	0.10	3.0

Calibration Position	Air or Water (A/W)	Ratio of Normal Force	Error in Normal Force Newtons	Ratio of Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm	Error in Friction Dir. deg
21	A	1.08	2.6	0.66	-2.0	2	6	-12
22	A	1.09	4.5	0.44	-2.7	-26	6	
23	A	1.06	5.2	1.19	1.1	-42	-1	
25	A	1.04	5.4	0.69	-3.2	10	9	-16
25	W	0.95	0.9	1.26	0.6	18	14	
26	A	1.12	6.9	0.33	-3.1	19	8	
26	W	1.14	6.4	1.12	0.3	8	15	
27	A	1.03	5.0	0.59	-4.3	-6	4	-52
27	W	1.02	3.5	0.76	-0.5	-10	6	
28	A	0.94	1.1	0.60	-2.2	-10	-8	
29	A	0.99	3.1	0.71	-3.3	2	0	-15
29	W	1.02	2.5	1.61	8.0	10	3	
30	A	0.96	1.3	0.47	-2.3	-12	-1	
32	A	0.74	-5.5	0.69	-4.0	-2	-14	
Minimum		0.74	-5.5	0.33	-4.3	-42	-14	-52
Maximum		1.09	6.9	1.61	1.1	19	15	-12
Mean		1.01	3.1	0.79	-1.3	-3	3	-16
Stand. Dev.		0.10	3.1	0.36	3.2	17	8	20

5.2.3 Internal Calibration Results

The objective of this level of calibration was to measure the response of the segment to loads in the normal axes and to record coupling between load cells. The tensions were applied by the two tension links. Three tests were conducted with each tension link and the results are presented in Table 5.3.A and 5.3.B. The segment response to the applied load has been expressed in ratio form. If the response is in the same plane as the force the ideal ratio is 1.0 and if it is not then the ideal ratio is 0 indicating that coupling is not present.

The results indicate that the only coupling present is in the longitudinal direction when a force is present in the HV direction. When the longitudinal-vertical tensioning, RV, was applied the longitudinal response was lower than the applied force at averages for the three tests of 0.84, 0.70 and 0.68 of the longitudinal load. The vertical response was also lower at average ratios of 0.93, 0.85 and 0.87 to the applied vertical force. It is possible that the tension link was twisting between its coupling and this caused it to record a larger load than that applied.

The segment responded better to the horizontal-vertical tensions. The horizontal response averages for the three tests were 1.00, 0.87 and 0.98 of the applied horizontal loads and the vertical response averages were .91, .82 and .90 of the applied vertical load.

5.2.4 Linearity and Hysteresis

These tests were carried out at calibration points 28 and 30 using the procedure discussed in Chapter 4. The results of the test were plotted and the zero stability, nonlinearity and hysteresis were calculated from the plots using the definitions given in Appendix F. The plots are presented in Appendix E.1. The zero stability, nonlinearity and hysteresis are given in Table 5.4. From Table 5.4 it can be seen that the segment behaves poorly in the x direction: nonlinearities of 6% and 27% and hysteresis of 6% and 17%. However only low loads were applied in this direction. In the other two directions the response is less than 6% except for one test in which less than 6N of force was applied in the y direction. The nonlinearity and hysteresis were then 6 and 10% but these correspond to load values of less than 1N which is near the limits of the horizontal transducer sensitivity.

TABLE 5.3a
SEGMENT 1 - INTERNAL CALIBRATIONS

RV TENSIONING

<u>TEST 1</u>						
Applied Load, N	40.1	56.0	55.0	68.6	90.0	A.R.R.*
<u>longitudinal response</u> <u>applied longitudinal load</u>	.86	.86	.79	.86	.85	.84
<u>horizontal response</u> <u>total applied load</u>	-.01	-.01	-.01	-.01	-.01	-.01
<u>vertical response</u> <u>applied vertical load</u>	.95	.92	.92	.92	.92	.93
=====						
<u>TEST 2 (in water)</u>						
Applied Load, N	5.2	9.5	52.0	80.3	99.0	A.R.R.
<u>longitudinal response</u> <u>applied longitudinal load</u>	.63	.72	.59	.73	.73	.70
<u>horizontal response</u> <u>total applied load</u>	negligible					.0
<u>vertical response</u> <u>applied vertical load</u>	.79	.89	.87	.86	.86	.85
=====						
<u>TEST 3 (in water)</u>						
Applied Load, N	40.8	74.8	25.0	6.3	-31.4	A.R.R.
<u>longitudinal response</u> <u>applied longitudinal load</u>	.69	.72	.73	.50	.71	.68
<u>horizontal response</u> <u>total applied load</u>	.01	.0	.01	.10	-.03	.0
<u>vertical response</u> <u>applied vertical load</u>	.86	.86	.86	.89	.87	.87

A.R.R. = Average Response Ratio						

TABLE 5.3b

SEGMENT 1 - TENSIONING CALIBRATIONS

HV TENSIONING

=====

TEST 1

Applied Load, N	17.5	17.2	34.0	35.3	A.R.R.*
-----------------	------	------	------	------	---------

<u>longitudinal response</u>	0.00	0.00	0.00	0.00	0.00
total applied load					

<u>horizontal response</u>	1.01	0.98	1.01	1.01	1.00
applied horizontal load					

<u>vertical response</u>	0.91	0.91	0.91	0.92	0.91
applied vertical load					

=====

TEST 2 (in-water)

Applied Load, N	31.1	29.5	50.6	89.3	32.8	A.R.R.
-----------------	------	------	------	------	------	--------

<u>longitudinal response</u>	-.05	-.06	-.02	-.03	-.06	-.04
total applied load						

<u>horizontal response</u>	0.80	0.84	0.84	0.87	1.01	0.87
applied horizontal load						

<u>vertical response</u>	0.80	0.80	0.82	0.82	0.87	0.82
applied vertical load						

=====

TEST 3 (in-water)

Applied Load, N	18.1	71.5	90.8	30.3	A.R.R.
-----------------	------	------	------	------	--------

<u>longitudinal response</u>	-.02	-.04	-.04	-.10	-.04
total applied load					

<u>horizontal response</u>	0.78	0.87	0.89	1.39	0.98
applied horizontal load					

<u>vertical response</u>	0.82	0.85	0.86	1.08	0.90
applied vertical load					

=====

*A.R.R. - Average Response Ratio

TABLE 5.4

SEGMENT 1 NONLINEARITIES

LOADS APPLIED AT POSITION 28:

FORCE	MAXIMUM MEASURED FORCE N	ZERO STABILITY	LINEARITY	HYSTERESIS
F_x	8.81	-	6%	6%
F_y	13.2	-	6%	4%
F_z	25.4	-	2%	3%
F_{TOT}	30.3	-	≤1%	≤1%

LOADS APPLIED AT POSITION 30:

FORCE	MAXIMUM MEASURED FORCE N	ZERO STABILITY	LINEARITY	HYSTERESIS
F_x^*	3.1	-	27%	17%
F_y	5.1	11%	6%	10%
F_z	11.8	2%	3%	3%
F_{TOT}	13.2	≤1%	3%	3%

* low force applied

The overall response of segment 1 was good: nonlinearities of 3% or less and hysteresis of 3% or less. These performance figures are those of the total segment and should not be confused with those of the individual transducers, which are less than generally accepted figures of 1%.

5.3 Segment 2 Calibration Results

5.3.1 Preliminary Calibrations

Segment 2 has been calibrated twice and both sets of results are presented for completeness although they are separate in themselves. The first set of calibrations, which includes external calibrations at 15 points both in-air and in-water and several internal calibrations, have been labelled the preliminary calibrations. Because the support system of segment 2 was the first to be modified the segment was completely tested to evaluate the success of the support system before modifications to Segment 1 and 3 began. Further modifications to this segment have altered its response to the extent that the preliminary calibrations will be only briefly discussed. One of the most important results of these calibrations is the comparison of in-water and in-air calibration methods.

The calibrations which correctly describe the response for the segment configuration used during ice testing are the final calibrations - internal and external. These have been conducted after the final modifications to segment 2 - namely the removal of the rear vertical transducer V_{21} - were completed, and are discussed in the following subsections.

The preliminary calibrations consisted of internal and external calibration tests.

The results of the preliminary internal calibration (reported in Appendix G.1), indicated a 12% overprediction of force in the vertical transducers. By using the moment equations it was deduced that the two forward transducers V_{22} and V_{23} were in error and a correction was applied by using the multipliers 0.78 and 0.86, respectively. These factors corrected the error and were used on the measurements of V_{22} and V_{23} made during the preliminary external calibrations.

The result sheets from the external calibration as well as the table summarizing the results are given in Appendix G.2. During these calibrations the force in the x direction was underpredicted on average by 41% with a standard deviation of 13%. The force in the y direction was overpredicted by 8% with a standard deviation of 10% and the forces in the z direction were underpredicted by 19% with a deviation of 5%. The success of the segment at predicting the applied load was found to depend on the location of the applied load. In general, the load was better predicted above the 22'WL than below it.

Based on the entire set of preliminary calibrations performed on the segment, correction factors were applied to the outputs of Segment 2's transducers in order that they better predict the applied load.

As ice loads are expected to occur primarily above the 23' WL correction factors derived for this area of the segment were used. The correction factors essentially removed the mean error found during external calibrations. It did not affect the random component of the error. The correction factors are summarized in Appendix G.3. A summary of the segment calibrations with the correction factors applied is also presented in Appendix G.3.

During the preliminary calibrations of segment 2, fifteen positions were calibrated on the segment both in-air and in-water. These two sets of calibrations are compared to see if one method of calibration produces different results than the other.

In order to examine the success of each method of calibration it is useful to examine the differences between the applied loads and the measured loads in the three principal planes. This examination was made before correction factors were applied. The average ratio of measured longitudinal force to applied longitudinal load was slightly lower during the in-air calibration 0.57 versus 0.61 for the in-water. The in-water calibration had the highest error in the horizontal load with a ratio of 1.10 versus 1.06 for the in-air, but had average ratios of 0.83 in the vertical direction versus 0.80 for the in-air. These results are summarized in Table 5.5. Generally no distinct trend except the notable increase in error of the horizontal load can be observed when comparing the in-water to the in-air calibrations. The increase in deviation of horizontal loads during the in-water calibration could be a result of fluctuating hydrodynamic loads on the hull since these are principally in the horizontal direction. The in-water calibrations generally have a greater standard deviation in the ratio of measured force to applied force possibly indicating the influence of fluctuating undetermined external loads or difficulties in positioning the applied load.

The accuracy in determining the position of the load is much improved in the in-air calibrations. If the standard deviation of the average error is compared; it is 8mm in the z direction versus ± 15 mm during in-water calibrations and ± 10 mm in the x direction was more than doubled during the in-water calibrations to ± 24 mm. The probable cause of the difference is the inability to see the point of load application and verify that it is correct during the in-water calibrations.

On the basis of these results it was concluded that since the errors in load cell measurements did not seem to be particularly biased towards one method of calibration and the errors in the location of the load were lower during the in-air calibration it was probably sufficient to only conduct extensive calibration in-air and perform several spot checks in-water to verify the in-air calibration.

TABLE 5.5

COMPARISON OF IN-AIR AND IN-WATER UNCORRECTED PRELIMINARY CALIBRATION RESULTS

	% ERROR in F_x	% ERROR in F_y	% ERROR in F_z	ERROR in x position	ERROR in z position
AIR					
mean	-43	60	-20	17	-8
std.dev.	14	7	4	10	8
WATER					
mean	-39	10	-17	19	-3
std.dev.	12	12	6	24	15
OVERALL					
mean	-41	8	-19	18	-6
std.dev.	13	10	5	17	12

5.3.2 Final External Calibrations

From the analysis of the preliminary calibrations it was decided that segment 2 would perform as well and perhaps better if one of the rear vertical load cells was removed.

This change resulted in a substantial change to the segment response particularly in the z direction. These changes in segment response document the complexity of the segment support system.

Three points were calibrated in-air and six in-water. Fewer points were calculated in air as the ice testing schedule dictated that the model be put in the water in preparation for the ice test. It was not anticipated that the segment response would change so time was not available for more calibrations. The results of these final calibrations are presented in Table 5.6. Preliminary calibrations performed at the same position have been tabulated in Table 5.7 in order that the two sets of calibrations may be compared. Note that these are uncorrected results in both cases. The result sheets for the tests are given in Appendix D.2.

The average ratio of measured force to applied force in the x direction has increased from 0.59 to 0.74. This means that on the average the measured force was 0.74 of the applied force. The increase in the ratio could be the result of a reduction in friction since now friction can only occur at 5 transducers versus 6 before. The standard deviation of the error has slightly increased from 0.14 to 0.18. Now the majority of the response is within the bounds 0.56 to 0.92, of the applied load versus 0.45 to 0.73 from the earlier calibrations. The mean ratio of the horizontal measured force to applied and its standard deviation has decreased slightly to 1.09 and 0.08. The ratio of the forces in the z direction went from less than 1.0 (0.80) to a value greater than 1.0, 1.09. The standard deviation is also larger in the new calibrations; 0.15 compared to 0.05. The mean ratio in the normal force also increased (0.89 to 1.00) as a result of the changes in the x and z directions. The standard deviation is now slightly higher. The friction force now has a positive error with a mean ratio of 1.22 but the standard deviation has not changed significantly. The error in locating the force has stayed approximately the same with the standard deviation of the error almost doubling in the x position.

Basically the ratios in Segment 2 were closer to 1.0 in the final testing but the standard deviations were slightly higher. This may be a result of the small sample size (10 calibrations). The largest change was in the measured vertical forces which are now over predicted by the segment. This can be attributed to the removal of the transducer V_{21} which was a rear vertical cell.

Table 5.6 Summary of Final Uncorrected Segment 2 Calibration Results

Calibration Position	Air or Water (A/W)	Total Applied Force Newtons	Ratio of Fx	Error in Fx Newtons	Ratio of Fy	Error in Fy Newtons	Ratio of Fz	Error in Fz Newtons
4	A	22.7	0.33	-8.3	1.23	3.0	1.23	3.6
4	W	33.2	0.52	-7.4	1.08	1.9	1.25	4.9
5	A	38.6	0.76	-1.3	1.04	0.9	1.14	4.2
5	W	32.1	0.73	-3.7	1.08	1.8	1.24	4.0
8	A	33.8	0.89	-0.4	1.01	0.2	1.09	2.7
8	W	42.1	0.74	-3.9	1.05	1.1	1.21	6.6
9	W	36.2	0.75	-3.1	1.08	1.4	0.99	-0.3
10	W	32.2	0.83	-1.9	1.01	0.2	0.93	-1.8
11	W	35.2	1.03	0.3	1.22	2.6	0.82	-5.9
11	W	28.1	0.81	-1.8	1.16	2.2	1.00	0.0
Maximum		42.1	1.03	-0.4	1.23	3.0	1.25	6.6
Minimum		22.7	0.33	-7.4	1.01	0.2	0.82	-5.9
Mean		33.8	0.74	-3.0	1.09	1.5	1.09	1.8
Standard Dev.		6.6	0.19	2.5	0.08	0.9	0.15	3.8

Calibration Position	Air or Water (A/W)	Ratio of Normal Force	Error in Normal Force Newtons	Ratio of Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm	Error in Friction Direction deg
4	A	1.12	2.5	1.19	3.4	75	24	37
4	W	1.04	1.4	1.38	2.3	64	13	
5	A	1.08	2.9	1.20	2.7	33	9	6
5	W	1.07	2.4	0.85	-0.5	54	11	
8	A	1.04	1.4	1.25	2.8	-8	-7	-5
8	W	1.09	3.7	2.80	6.4	-23	6	
9	W	0.99	-0.3	1.02	0.1	23	-9	
10	W	0.64	-1.8	0.89	-0.6	22	-17	
11	W	0.92	-2.5	0.52	-5.8	12	1	10
11	W	1.02	0.5	1.07	0.3	-10	-7	
Maximum		1.12	2.9	2.80	6.4	75	24	37
Minimum		0.92	-2.5	0.52	-5.8	-23	-17	-5
Mean		1.00	1.0	1.22	1.1	24	2	12
Standard Dev.		0.14	2.0	0.61	3.2	33	12	

Table 5.7 Summary of Preliminary Uncorrected Segment 2 Calibration Results

Calibration Position	Air or Water (A/W)	Total Applied Force Newtons	Ratio of Fx	Error in Fx Newtons	Ratio of Fy	Error in Fy Newtons	Ratio of Fz	Error in Fz Newtons
4	A	84.7	0.33	-19.2	1.08	4.7	0.86	-8.0
4	W	93.6	0.68	-7.2	1.02	1.2	0.75	-14.4
5	A	68.1	0.36	-14.8	0.96	-1.7	0.81	-9.5
5	W	79.5	0.76	-6.2	0.92	-4.5	0.89	-5.4
8	A	80.4	0.58	-13.6	1.11	4.7	0.77	-13.5
8	W	84.5	0.66	-10.6	1.10	4.6	0.89	-7.1
9	A	67.4	0.52	-11.0	1.17	5.5	0.78	-11.9
9	W	79.4	0.57	-13.2	1.05	2.4	0.74	-15.1
10	A	82.0	0.61	-11.8	1.11	4.8	0.46	-14.8
10	W	84.5	0.70	-11.7	1.26	10.5	0.77	-14.4
11	A	32.4	0.75	-3.4	1.16	2.9	0.81	-4.4
11	W	43.3	0.58	-6.1	1.40	6.6	0.77	-8.5
Maximum		93.6	0.76	-3.4	1.40	10.5	0.89	-4.4
Minimum		32.4	0.33	-19.2	0.92	-4.5	0.74	-15.1
Mean		73.3	0.59	-10.7	1.11	3.5	0.80	-10.6
Stand. Dev.		18.2	0.14	4.4	1.13	3.9	0.05	3.9

Calibration Position	Air or Water (A/W)	Ratio of Normal Force	Error in Normal Force Newtons	Ratio of Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm
4	A	0.94	-4.7	0.76	-6.2	26	6
4	W	0.91	-7.4	0.42	-21.4	32	43
5	A	0.83	-11.3	0.83	-3.6	24	-10
5	W	0.90	-7.9	0.53	-4.6	35	12
8	A	0.86	-11.0	0.96	-0.3	22	-18
8	W	0.93	-5.7	0.76	-3.0	-17	5
9	A	0.89	-6.8	0.58	-8.9	23	-12
9	W	0.85	-11.6	0.38	-10.6	43	-1
10	A	0.86	-11.0	0.70	-3.9	1	-9
10	W	0.92	-6.6	0.11	-16.4	10	-1
11	A	0.92	-2.6	3.06	2.8	-6	-7
11	W	0.89	-4.6	0.56	-4.8	20	-12
Maximum		0.94	-2.6	3.06	2.8	43	43
Minimum		0.83	-11.6	0.11	-21.4	-17	-18
Mean		0.89	-7.6	0.80	-6.7	18	0
Stand. Dev.		0.03	3.0	0.75	6.7	18	16

A conclusion which can be drawn from the results is that the error is more dependent on the magnitude of the force rather than on an absolute error. In the final calibration, applied forces were a little less than half of those applied during preliminary calibrations and correspondingly the mean error and standard deviation has dropped in all cases. Theoretically, if the average applied forces and measured forces are halved then the mean error and the mean standard deviation should be halved as well. It can be seen that the results are even better than this: in the x direction the mean error dropped from -10.7N to -2.9N and the standard deviation decreased from 4.4 N to 2.5N. The results have been more than halved. Therefore the increase in standard deviation of the ratio may not be significant since the standard deviation of the error decreased to less than half of the standard deviation of the preliminary calibrations.

It is also worthwhile to note that the mean values and standard deviations of the 12 selected positions from the preliminary calibrations are essentially the same as those of the entire group of 30 calibrations with a few minor exceptions.

5.3.3 Final Internal Calibration

Because of the change in the response of segment 2 to normal loads several internal calibrations were performed following the procedure outlined in section 5.1 to see if they would also record a change in the segment response. The results are presented in Table 5.8.

Previously the vertical transducers measured 1.14 of the applied vertical tension and they now measured only 1.03 of the tension. Because of this reduction and the change in the vertical transducer configuration there was not justifiable reason for leaving the correction factors of 0.86 on V_{22} and 0.78 on V_{23} in place, and they were removed.

The only coupling present was in the vertical direction when a longitudinal load was applied. A correction applied to the calibration results to account for this coupling did not decrease the standard deviation of the error so the correction was removed. From the changes in the response of segment 2 it appears that the interaction between load cells is quite complex.

5.3.4 Nonlinearities and Hysteresis

One test was carried out at position 5 on the segment following the procedure outlined in Section 5.1. This test was conducted with four rear vertical cells before one of the rear vertical cells was removed. The results were plotted and are presented in Appendix E.2.

TABLE 5.8
SEGMENT 2 TENSIONING CALIBRATIONS

LONGITUDINAL TENSIONING

Applied Load, N	16.7	26.8	34.1	A.R.R.*
<u>longitudinal response</u> <u>applied longitudinal load</u>	0.64	0.67	0.67	0.67
<u>horizontal response</u> <u>applied longitudinal load</u>	0.00	0.00	0.00	0.00
<u>vertical response</u> <u>applied longitudinal load</u>	0.05	0.11	0.11	0.09

HORIZONTAL TENSIONING

Applied Load, N	24.5	57.3	70.1	102.9	123.7	A.R.R.
<u>longitudinal response</u> <u>applied horizontal load</u>	0.00	0.00	0.00	0.00	0.00	0.00
<u>horizontal response</u> <u>applied horizontal load</u>	0.89	0.91	0.92	0.93	0.94	0.92
<u>vertical response</u> <u>applied vertical load</u>	0.04	0.01	0.02	0.04	0.04	0.03

VERTICAL TENSIONING

Applied Load, N	34.2	86.2	122.6	138.8	A.R.R.
<u>longitudinal response</u> <u>applied vertical response</u>	0.00	0.00	0.00	0.00	0.00
<u>horizontal response</u> <u>applied vertical response</u>	0.00	0.00	0.00	0.00	0.00
<u>vertical response</u> <u>applied vertical response</u>	1.01	1.03	1.04	1.04	1.03

* A.R.R. - Average Response Ratio

The zero stability, linearity and hysteresis, as calculated from the definitions presented in appendix F are given in Table 5.9. The behaviour of the segment is good except for its overall hysteresis which is 6% for a maximum measured force at 45.3N. While the hysteresis was high in the x direction, 13%, its absolute value was about 1N which is rather low. The linearity was low, 3% or less, in all directions except the x direction and the zero stability was low, 3% or less, or in absolute terms less than 1N in all directions.

5.4 Segment 3 - Calibration Results

5.4.1 External Calibrations

Segment 3 was calibrated in-air at the 11 points indicated in Figure 4.11, and in-water at the points on the 23' and 22' waterlines. The result sheets from the calibration tests are given in Appendix D.3. In Table 5.10 the calibration results are summarized.

Segment 3 is almost flat especially at the aft end in the vicinity of $x = 0.89m$. At the aft end of the segment, the segment surface is almost parallel to the centreline bulkhead. Therefore normal forces have very little vertical or longitudinal components. In the case of the longitudinal force, it is possible that if either the calibration rig angle α or the hull angle α is in error by more than 1° the longitudinal force applied can be in the negative direction. Referring to Figure 4.7 in Section 4 it can be seen that for an error in the waterplane angle α of 2° when α is less than 5° the error between predicted force and actual applied force in the longitudinal direction is 22%. Therefore because of the large calibration rig errors the measurements of longitudinal force cannot realistically be compared to the predicted longitudinal force.

From Table 5.10 it can also be seen that at point 44, where the segment is most vertical, there are large errors in the vertical force and in the z position of the force. This is most likely because of the low vertical component of the applied normal force at this point. The vertical normals at this point is 0.127 so the vertical load is 12.7% of the normal force. All the calibration results indicated by a "*" are believed to have large errors due to errors in applying the force at the correct angles.

TABLE 5.9

SEGMENT 2 NONLINEARITIES - MEASURED AT POSITION 5

FORCE	MAXIMUM MEASURED FORCE N	ZERO STABILITY	LINEARITY	HYSTERESIS
F_x	7.6	0	7%	13%
F_y	31.5	3%	3%	5%
F_z	31.6	2%	3%	3%
F_{TOT}	45.3	2%	2%	6%

Table 5.10 Summary of Uncorrected Segment 3 Calibrations

Calibration Position	Air or Water (A/W)	Total Applied Force Newtons	Ratio of Fx	Error in Fx Newtons	Ratio of Fy	Error in Fy Newtons	Ratio of Fz	Error in Fz Newtons
42	A	23.5	-0.26	1.7	0.96	-0.8	1.03	0.3
44	A	31.1	1.76	-0.4	0.87	-3.7	0.44	-7.1
44	W	35.4	-0.51#	-4.9	0.90	-3.5	0.60	-3.0
45	A	30.8	3.87	3.7	0.93	-1.7	0.98	-0.4
45	W	37.1	1.09	0.7	0.98	-0.4	0.70	-4.6
46	A	28.2	0.85	-0.5	0.98	-1.3	0.95	-1.3
46	W	34.9	0.85	-1.9	0.95	-3.7	0.87	-2.4
47	A	27.1	0.94	-0.1	0.86	-4.2	0.60	-5.9
47	W	31.4	-0.39#	-4.3	0.97	-0.9	0.84	-1.4
48	A	46.2	2.58	3.5	0.90	-3.8	0.99	-0.3
48	W	36.3	0.98	-0.2	0.95	-1.6	0.69	-4.1
49	A	36.9	1.03	0.3	1.00	0.1	0.92	-1.7
49	W	23.2	0.99	0.0	1.00	0.0	0.86	-1.9
50	A	36.0	0.88	0.1	0.93	-2.5	0.82	-2.2
50A	A	31.7	2.25#	-0.3	0.96	-1.2	0.75	-2.8
51	A	39.5	1.49	2.8	0.94	-1.8	0.92	-1.8
52	A	25.5	1.15	0.9	1.07	1.0	0.93	-1.5
54	A	36.4	1.58	2.7	0.96	-1.2	0.95	-1.1
Minimum		23.2	-0.51	-4.9	0.86	-4.2	0.44	-7.1
Maximum		46.2	2.58	3.5	1.07	1.0	1.03	-0.3
Mean		32.8	1.17	0.2	0.95	-1.7	0.82	-2.4
Stand. Dev.		6.0	0.05	2.3	0.05	1.5	0.16	1.9

Calibration Position	Air or Water (A/W)	Ratio of Normal Force	Error in Normal Force Newtons	Ratio of Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm	Error in Friction Dir. deg
42	A	0.99	-0.2	0.80	-1.5	69	11	-4
44	A	0.85	-4.5	0.21	-7.1	-10	72#	35
44	W	0.89	-3.9	0.47	-1.9	-10	56#	
45	A	0.98	-0.7	0.85	-1.6	35	12	-18
45	W	0.96	-1.5	0.54	-3.2	24	-16	
46	A	0.96	-1.2	0.97	-0.3	-6	-6	1
46	W	0.92	-2.9	0.94	-0.3	-19	-16	
47	A	0.84	-4.5	0.52	-5.3	-1	0	9
47	W	0.96	-1.1	0.69	-1.7	19	-7	
48	A	0.94	-2.4	0.82	-2.4	54	11	-11
48	W	0.93	-2.8	0.55	-2.1	26	-17	
49	A	0.98	-0.6	0.83	-1.0	-6	-8	
49	W	0.96	-0.9	0.61	-1.3	-6	-8	
50	A	0.92	-2.8	0.77	-1.8	-8	-13	0
50A	A	0.95	-1.5	0.60	-2.6	-1	1	9
51	A	0.97	-1.2	0.76	-2.7	45	6	-15
52	A	0.99	-1.3	0.96	-0.4	-1	-30	-6
54	A	0.98	-0.6	0.77	-2.3	37	7	-14
Minimum		0.84	-4.5	0.21	-0.3	-19	-30	35
Maximum		0.99	-0.2	0.97	-7.1	54	72	-18
Mean		0.94	-1.9	0.70	-2.2	13	-1	-1
Stand. Dev.		0.04	1.4	0.20	1.7	26	25	16

Large error due to small waterplane angle

Segment 3 produced similar results to those obtained from segment 1. The errors in forces measured in the y and z directions are small with both consistent and random errors. In the y direction the average ratio of measured forces to applied forces is 0.95 and the standard deviation is 0.05. Without the correction factors the majority of the results in the horizontal direction are within 90% to 100% of the applied force. On segment 3 the lowest proportion of the normal force which could be applied in the horizontal direction is 73% while the highest is 99% so the segment has very good response in the direction where at least 73% of the normal force is applied. This suggests good success of the segment instrumentation. The errors in the vertical direction are slightly higher. The average error is -2.4 N and the standard deviation is 1.9 N.

The x forces have larger errors in terms of force ratios but the error is never greater than 5N in the 12 cases analysed. If the two calibrations of point 44 are ignored on the basis of probable high error due to small waterplane angle then the position errors on this segment range up to 54mm and the standard deviation in these errors is 26mm in the x direction and 10mm in the z direction.

The majority of the tests predicted normal force to within ± 0.04 of 0.94 of the applied normal load. The maximum error observed was 4.5N. On the average the friction force was underpredicted by 2.2N and the standard deviation was 1.6N, a negligible amount.

5.4.2 Internal Calibrations

The objective of the tensioning calibrations was to measure the response of Segment 3 to loads in the x, y and z axes. Five tests were carried out: one in each of the three directions in-air and a vertical and horizontal test with the model in the water. Segment 3 has two vertical tension links but applying a load on both at the same time would not pinpoint clearly any errors in the segment response so loads were applied on each in separate tests. Arbitrarily the vertical load was applied by transducer V_{36} during in-air tests and by V_{35} during in-water tests.

The results are presented in Table 5.11. The segment response to the applied load has been expressed in ratio form. If the response is in the same plane as the force, the ideal ratio is 1.00, and if it is not, the ideal ratio is 0.00, indicating that coupling between transducers is not present.

The horizontal response of the segment was slightly less than the applied force (2.5%) while the vertical response was slightly more than that applied (3-4%) but neither of these errors are significant. The horizontal tensioning test indicated a coupling between the horizontal and longitudinal transducers. The longitudinal transducers were reading 6% of the applied horizontal load.

TABLE 5.11

SEGMENT 3 INTERNAL CALIBRATIONS

LONGITUDINAL TENSIONING

Applied Load, N	13.7	16.1	45.9	57.7	10.4	A.R.R.
<u>longitudinal response</u> <u>applied longitudinal load</u>	.87	.91	.95	.97	1.22	.98
<u>horizontal response</u> <u>applied longitudinal load</u>	.02	.02	.01	.01	-.02	.01
<u>vertical response</u> <u>applied longitudinal load</u>	-.03	-.03	-.01	-.01	.02	-.01

HORIZONTAL TENSIONING

Test 1						
Applied Load, N	22.7	38.1	56.7	70.6	69.6	A.R.R.
<u>longitudinal response</u> <u>applied horizontal load</u>	.04	.06	.07	.08	.07	0.06
<u>horizontal response</u> <u>applied horizontal load</u>	.98	.97	.97	.98	.99	0.98
<u>vertical response</u> <u>applied vertical load</u>	-.02	0	.01	0	0	0
Test 2						
Applied Load, N	23.4	64.6	87.9	127.7		A.R.R.
<u>longitudinal response</u> <u>applied horizontal load</u>	.04	.05	.08	.07		0.06
<u>horizontal response</u> <u>applied horizontal load</u>	.98	.98	.96	.96		0.97
<u>vertical response</u> <u>applied vertical load</u>	.10	.06	.05	.05		0.06

TABLE 5.11 CONTINUED
SEGMENT 3 INTERNAL CALIBRATIONS

VERTICAL TENSIONING

Applied Load (at V_{36}), N	23.7	64.7	37.4	15.4	16.0	A.R.R.
<u>longitudinal response</u> <u>applied vertical load</u>	.02	.01	.01	.02	.02	0.02
<u>horizontal response</u> <u>applied vertical load</u>	-.01	-.01	-.02	-.02	.01	-0.01
<u>vertical response</u> <u>applied vertical load</u>	1.01	1.0	1.04	1.09	1.05	1.04
Applied Load (at V_{35}), N	16.7	25.3	23.0	31.5		A.R.R.
<u>longitudinal response</u> <u>applied vertical load</u>	.01	0.00	0.00	0.00		0.00
<u>horizontal response</u> <u>applied vertical load</u>	-.02	-.02	-.03	-.02		-0.02
<u>vertical response</u> <u>applied vertical load</u>	1.0	1.02	1.05	1.03		1.03

In the longitudinal direction, there was some nonlinearities in the segment response, which are indicated when the ratio flips from a value less than 1.0 to a value greater than 1.0 or changes sign. However the average response in the longitudinal direction was almost 1.0 and the coupling in other directions was negligible.

5.4.3 Nonlinearities and Hysteresis

Three tests were carried out at the calibration points 47 and 49 using the stated procedures. The results were plotted and curves faired through the points in the order in which the loads were applied. The plots are given in Appendix E.3.

A summary of the nonlinearities and hystereses is presented in Table 5.12. It is shown that the segment response in the x direction seems to be poor but because of the low loads applied 5N or less, a hysteresis of 46% is actually only 1.4N. Hysteresis in absolute terms is only about 1N which is 2% of the transducer rating. Nonlinearity in the z direction was also high during one of the tests, 11%, but again this is less than 1N which is less than 2% of the vertical transducer ratings.

The overall response of the segment was good: nonlinearities of 3 to 5% or 0.5 to 1N at the loads tested and hysteresis of 3-7% or 0.5 to 1.5N. Any load less than 2N can be considered negligible and it can be concluded from these tests that segment 3 cannot measure with any degree of accuracy, loads less than 2N.

The conclusion reached is that 1N nonlinearities or hysteresis are present in each direction of force application in segment 2 resulting in an overall value of 2N.

5.5 Calibration Rig Verification Results

5.5.1 Isolation of Rig Errors

The measurements were compared by using the ratios of measured values to applied values where a ratio of 1.0 would mean perfect agreement between the calibration rig blocks and the triaxial blocks. The results in ratio form for the angle tested were plotted for F_x , F_y , F_z and F_{TOT} . The plots are given in Appendix D.4.

The error measured during the calibration rig verification has been compared to the errors measured during segment calibrations in Table 5.13 and graphically in Figure 5.1. Only the segment calibrations which had an applied friction factor of less than 0.3 are used for comparison. The mean and range of results obtained are shown for force components in the three principal axis of the model. From the mean errors plotted described in this manner an attempt has been made to deduce the error which can be attributed to the segment itself.

TABLE 5.12

SEGMENT 3 NONLINEARITIES

LOADS APPLIED AT POSITION 47:

FORCE	MAXIMUM MEASURED FORCE N	ZERO STABILITY	LINEARITY	HYSTERESIS
F_x	3.1	-	46%	46%
F_y	24.1	-	4%	4%
F_z	8.8	-	11%	3%
F_{TOT}	25.8	-	5%	7%

LOADS APPLIED AT POSITION 49:

FORCE	MAXIMUM MEASURED FORCE N	ZERO STABILITY	LINEARITY	HYSTERESIS
F_x	3.9	-	11%	17%
F_y	15.6	-	3%	2%
F_z	15.7	-	2%	6%
F_{TOT}	22.6	-	3%	3%

TABLE 5.13
CALIBRATION ERRORS

SEGMENT 2

	$\bar{\epsilon}_{TOT}$		$\bar{\epsilon}_{RIG}$		$\bar{\epsilon}_{SEG}$		APPROX. LEVEL OF FORCES MEASURED, N
	MEAN	RANGE	MEAN	RANGE	MEAN		
F_x	.76	.60 - .90	1.25	1.1 - 1.5	49% low		10
F_y	1.08	1.01 - 1.15	.97	.94 - 1.00	11% high		20
F_z	1.12	0.97 - 1.25	0.94	0.92 - 0.96	18% high		18

SEGMENT 3

	$\bar{\epsilon}_{TOT}$		$\bar{\epsilon}_{RIG}$		$\bar{\epsilon}_{SEG}$		APPROX. LEVEL OF FORCES MEASURED, N
	MEAN	RANGE	MEAN	RANGE	MEAN		
F_x	1.13	.85 - 1.76	-	-0.5 - 1.76	-%		2
F_y	.95	0.87 - 1.00	0.96	0.99 - 0.95	-1% low		35
F_z	0.84	0.52 - 0.99	0.97	0.91 - 1.00	13% low		15

Legend: $\bar{\epsilon}_{TOT}$ = Total error measured on segment

$\bar{\epsilon}_{RIG}$ = Error attributable to calibration rig inaccuracies.

$\bar{\epsilon}_{SEG}$ = Error attributable to segment support system inaccuracies.

The error measured during calibration testing is the total error or the sum of the calibration rig error $\bar{\epsilon}_{RIG}$ and the segment error $\bar{\epsilon}_{SEG}$:

$$\bar{\epsilon}_{TOT} = \bar{\epsilon}_{RIG} + \bar{\epsilon}_{SEG}$$

$$\therefore \bar{\epsilon}_{SEG} = \bar{\epsilon}_{TOT} - \bar{\epsilon}_{RIG}$$

As values for $\bar{\epsilon}_{RIG}$ have been determined during the calibration rig verification the segment error should be deduced by subtracting $\bar{\epsilon}_{RIG}$ from the total error, $\bar{\epsilon}_{TOT}$.

As shown in Table 5.13, the result of this analysis is that in segment 3 the segment error in the y direction is almost zero, and causes a 13% underprediction in the z direction. The segment error in the x direction was not evaluated because the range of the calibration rig error was so large from a small set of data points that the uncertainty in the mean would be high. It should be noted that the calibration rig error completely overlaps the total segment error.

In segment 2 the segment error found from the analysis was a 49% under prediction of forces in the x direction an 11% and 18% overprediction of the forces in the x and z direction respectively. These results indicate that the segment response in the x, y and z direction is no better than would be predicted if no attempt was made to correct for the calibration rig response in this manner.

The calibration rig error has approximately the same width of range as the total error for the force. The calibration rig error is probably contributing to some or most of the deviation in the total error of F_x . This analysis has been conducted by comparing the mean values of each type of test and does not take into account the range of values about the mean. In Figure 5.1 the range of errors for each test are plotted for segment 2 and 3. The errors overlap on segment 3 and indicate that the calibration rig is contributing to the total errors. For segment 2 the errors do not overlap.

The comparison between the mean values of the total error and the calibration rig error may be affected by the distributions of waterplane and normal flare angles used for each type of test. If the distributions do not coincide, then the means are unlikely to coincide. A better estimate of the error may be obtained by directly measuring the calibration rig error at positions which correspond to those used in the segment calibrations.

5.5.2 Comparison of Total and Rig Errors at Specified Points

A comparison has been made between the errors measured in the calibration rig and the total measured error at corresponding calibration points. This has been carried out for two points on segment 2 and two points on segment 3 as indicated in Table 5.14.

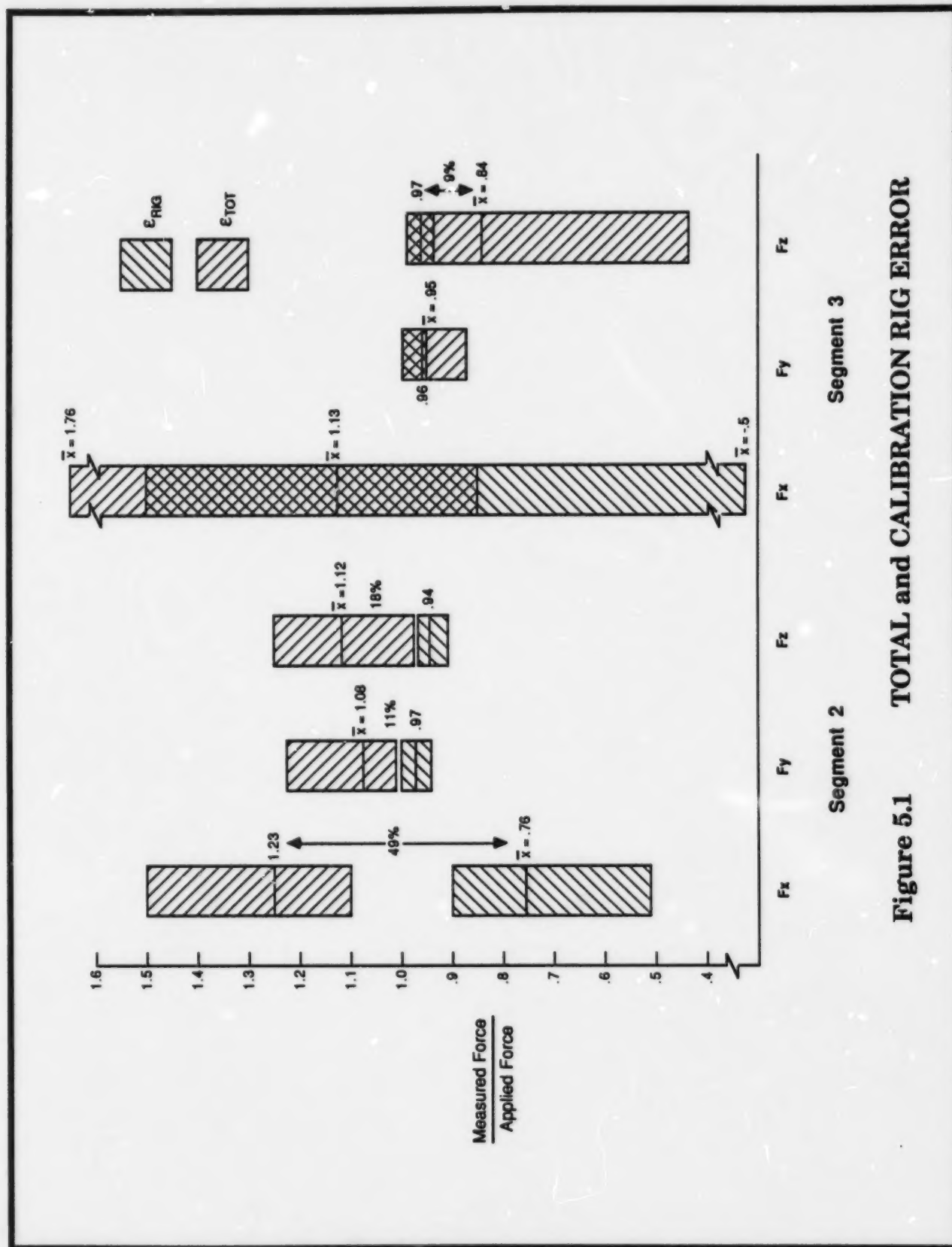


Figure 5.1 TOTAL and CALIBRATION RIG ERROR

TABLE 5.14

COMPARISON OF TOTAL AND RIG ERRORS AT SPECIFIED POINTS

SEGMENT 2

SEGMENT CALIBRATION POINT 1	F_x	F_y	F_z	F_{TOT}
$\bar{\epsilon}_{TOT}$	0.60	.93	0.86	0.89
Simulated $\bar{\epsilon}_{RIG}$	1.22	.95	0.94	0.95
$\bar{\epsilon}_{SEG}$	-0.62	-0.02	-0.08	-0.05
% error	62%	2%	-8%	-5%

SEGMENT CALIBRATION POINT 5

$\bar{\epsilon}_{TOT}$	0.76	1.04	1.14	1.08
$\bar{\epsilon}_{RIG}$	1.22	.95	0.94	0.95
$\bar{\epsilon}_{SEG}$	-0.26	-0.09	-0.20	-0.13
% ERROR	-25%	- 9%	-20%	-13%

SEGMENT 3

SEGMENT CALIBRATION POINT 51

$\bar{\epsilon}_{TOT}$	1.49	0.94	0.92	0.97
$\bar{\epsilon}_{RIG}$	1.53	0.98	0.98	0.98
$\bar{\epsilon}_{SEG}$	-0.04	-0.04	-0.06	-0.01
% ERROR	-4%	4%	6%	1%

SEGMENT CALIBRATION POINT 54

$\bar{\epsilon}_{TOT}$	1.58	.96	0.95	0.98
$\bar{\epsilon}_{RIG}$	1.39	.96	0.96	0.97
$\bar{\epsilon}_{SEG}$	-0.19	0	0.01	0.01
% ERROR	19%	0%	1%	1%

Considering the two points on segment 2, the segment errors of forces in the y and z directions as well as the total force are of similar magnitudes. At point 1 applied forces are underestimated by about 5% while at point 5 they are underestimated by about 13%. Segment errors in the x direction differ by greater amounts, however, this may be due to very low loads in this direction.

The points on segment 3 show better results but with similar trends. The total force, as well as the y and z components are overestimated by the segment by between 1 and 6%. The forces in the x direction show greater deviation but it is still quite low, only 4% in one case and 19% in the other.

In segment 3 the effect of including the rig errors has been to reduce the indicated segment error. A conclusion which may be drawn is that the rig error at each specified point should be taken into account to determine the segment error.

The effect of including the rig errors on segment 2 has been to slightly increase the errors. Where the total system underpredicted load the calibration rig overpredicted them and vice versa so that the segment error increased slightly over the total area.

The results of the two linearity tests were plotted for forces in the x, y and z directions (F_x , F_y , F_z) and the total force. These plots are available in Appendix E.4. From the plots the zero stability, linearity, and hysteresis were calculated using the definitions in Appendix F. The results as shown in Table 5.15 were very good. Hysteresis and nonlinearity of the calibration rig was less than 1% in all directions during one test and was at most 2% in the x and z directions in the other test. It can be concluded that the calibration rig was not the cause of the nonlinearities observed during the segment calibrations.

5.6 Assessment of Segment Accuracy

The overall performance of each segment was acceptable even though all three segments had a relatively poor response in the longitudinal direction. This is possible because the force in the longitudinal direction is the smallest component of the total force.

It is concluded that the errors observed during the hysteresis tests are random errors equivalent to the calibration errors in the segments since there seems to be a correspondence between the two. The nonlinearities are with one exception less than or equal to the standard deviations in normal and friction force and it must be kept in mind that these are the maximum nonlinearities not the average.

An in depth error analysis was conducted from the results of the segment internal calibrations and is reported in Appendix H. From this analysis it was concluded that most of the errors are spread around a constant mean error with a constant variance.

TABLE 5.15
CALIBRATION RIG HYSTERESIS

FORCE	MAXIMUM MEASURED FORCE (N)	ZERO STABILITY	LINEARITY	HYSTERESIS
Calibration rig angles: $\alpha = 26^\circ$, $\theta = 55^\circ$				
F_x	4.51	-	2%	2%
F_y	12.2	-	$\leq 1\%$	$\leq 1\%$
F_z	19.4	-	1%	2%
F_T	23.4	-	$\leq 1\%$	2%
Calibration rig angles: $\alpha = 23^\circ$, $\theta = 60^\circ$				
F_x	4.5	0	$\leq 1\%$	$\leq 1\%$
F_y	14.9	0	$\leq 1\%$	$\leq 1\%$
F_z	14.4	0	$\leq 1\%$	$\leq 1\%$
F_T	21.2	0	$\leq 1\%$	$\leq 1\%$

The only exception was some of the data for segment 3. A constant mean value for the error in F_x in segment 3 and a decreasing variance as the measured force increases was found. This can be seen in Table 5.10 where calibrations with a high percent error can have a lower absolute error than other calibrations. It was found that both F_y and F_z have an increasing error as the measured force increases.

Correction factors were calculated from the errors and are given in Table 5.16. By dividing the segment measured force by the appropriate correction factor the mean measured force will equal the applied force. The confidence interval of the measurement is determined by σ_y the standard deviation of the correction. Error bounds of $\pm\sigma_y$ around the corrected measured force result in a 68% confidence level. One has a confidence of 68% that the actual force lies within the bounds. Figure 5.2 shows these confidence limits about a corrected F_z measurement from segment 3 for an ice test time history.

Without applying any correction factors the segments can predict normal force on the average to within 10% or less of the applied force with the standard deviation being 13% or less. If correction factors are applied to the F_x , F_y and F_z measurements the error of the normal force will decrease. As an example the ratio of measured normal force to applied normal force decreased from 1.11 to 1.03 when F_z was corrected on segment 1.

The friction force can be predicted on the average to within 25% of the actual value with error bounds of $\pm 40\%$, 47% and 14% on segments 1, 2 and 3 respectively as shown in Appendix H.

Considering that prediction of ice loads to within bounds of $\pm 20\%$ are considered state of the art, the performance of the segments is adequate for the purposes of predicting normal force and friction force of ice loads.

Position of the force can be determined quite accurately by the segments 1 and 2. The x coordinate can be found to within $\pm 0.02m$ of the actual position on segments 1 and 2 and z to within $\pm 0.005m$ on segment 1 and $\pm 0.010m$ on segment 2.

Performance on segment 3 is not as accurate but the segment is almost twice as long as segment 2 in the x direction. The x coordinate can be found to within $\pm 0.03m$ and the z coordinate to within $\pm 0.02m$.

The direction of the friction force can be found to within $\pm 15^\circ$ for friction coefficients of .20 or more.

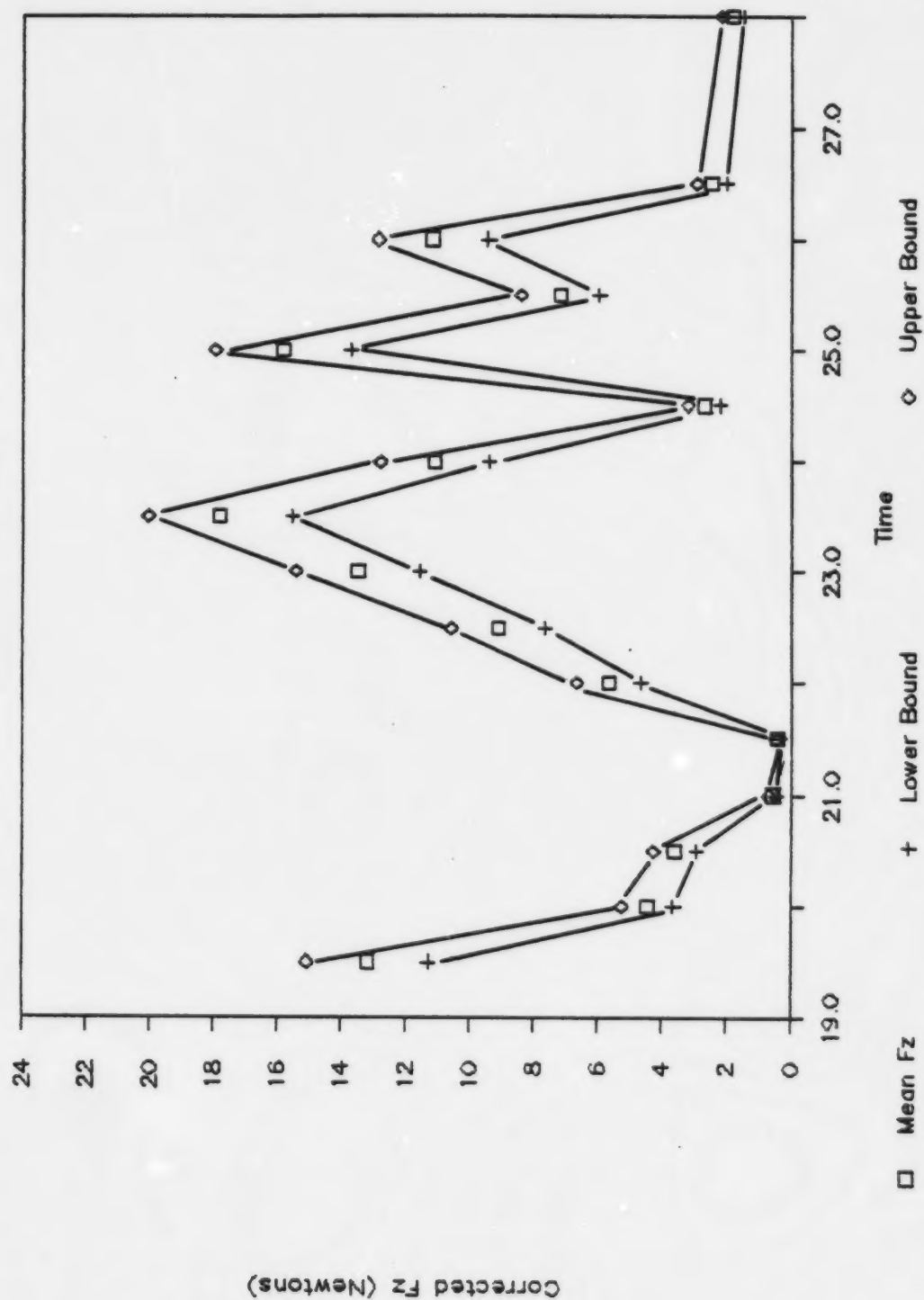
Furthermore, the calibration rig verification tests when compared to corresponding segment calibration tests had essentially the same errors inferring that some of part of the error measured during segment calibrations was caused by the calibration rig and not the segment. As well the calibration rig may be responsible for part of the deviation in error that occurred during segment calibrations.

TABLE 5.16
CORRECTION FACTORS AND STANDARD DEVIATION FROM THE SEGMENT
CALIBRATIONS

FORCE	SEGMENT 1		SEGMENT 2		SEGMENT 3	
	CORRECTION FACTOR	STD. DEV.	CORRECTION FACTOR	STD. DEV.	CORRECTION FACTOR	STD. DEV.
F_x	1.279	0.432	0.744	0.184	1.170	.6038 (-2X+2.6)*
F_y	1.036	0.074	1.094	0.077	0.950	0.048
F_z	1.132	0.117	1.090	0.142	.0202X+ .5486*	0.108

* where X is the measured force of interest.

FIGURE 5.2
EFFECTIVE BOUNDS ON CORRECTED Fz
(Segment 3, Test S32)



6. FLOATING MODEL CALIBRATIONS

Floating model calibration tests were conducted to determine the response of the segments to hydrodynamic forces and to ship motions which would occur if the model was freely towed. Two types of calibrations were involved: measuring the response to the ship motions of heave, pitch and roll with the model stationary and measuring the open water hydrodynamic load during towing at various speeds.

6.1 Model Response to Heave, Pitch and Roll

Movement of the model up or down or from side to side causes the segments either to be lifted partially out of the water or to be more submerged. Since the segments are neutrally buoyant when the model is at its design waterline, lifting a segment causes its weight to act on it, while submerging it causes a buoyant force to act on it.

The ship motions which cause lifting and submergence of the segments are heave, pitch, and roll. Heave is the vertical translation of the ship, pitch is the rotation of the ship vertically about its center of buoyancy and roll the rotation of the ship from side to side as shown in Figure 6.1 where the positive direction of each motion is shown. During ice testing in which the model is freely towed it will be necessary to subtract these loads due to ship motions from the total forces so that the forces applied by ice resistance may be determined.

The procedure for these tests was quite straight forward. One of the three parameters, pitch, heave or roll was varied at a time by adjusting the model's ballast. However these motions are coupled so it was not always possible to vary one without altering the other two. The model motion was recorded by a Linear Variable Differential Transformer (LVDT) and two angular potentiometers. Segment response was measured by the segment. Six values of heave were tested, two negative and four positive, with positive being down with non-dimensional heave to draft ratio of 0.043. Four values of pitch, two negative and two positive ranging from -3.4° to 2.1° were tested and six values of roll ranging from -7.5° to 9.8° . At the extreme values of pitch and roll, water was over the top deck of the model.

To analyze the data it was necessary to uncouple the motions. Fortunately pitch and roll did not occur during the heave tests and only during the pitch tests did significant coupling with the other two motions take place. Therefore by analyzing heave first and roll second it was possible to uncouple the heave which occurred during the roll tests and the heave and roll which occurred during the pitch tests.

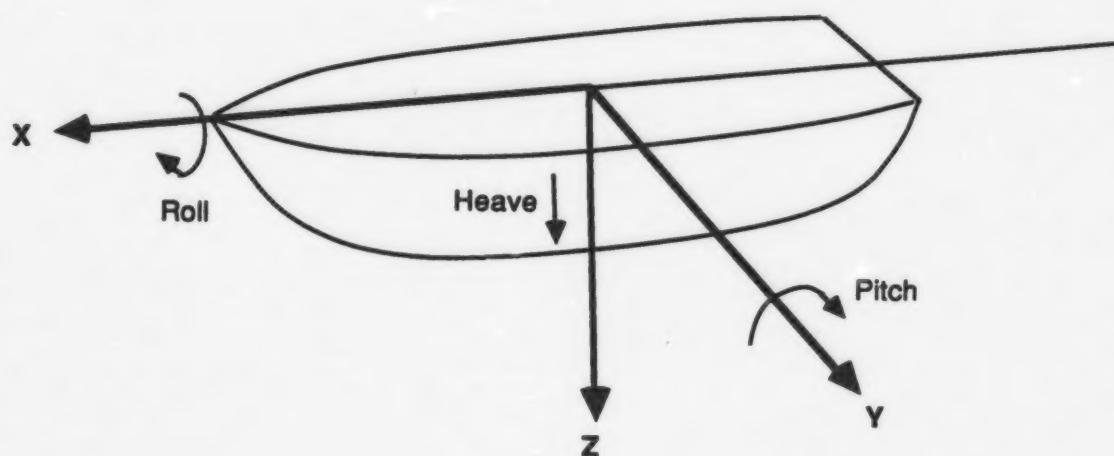


Figure 6.1 **DEFINITION OF HEAVE, PITCH and ROLL**

The results presented in Table 6.1 agree with intuition - the vertical transducers are most effected by heave, pitch and roll since any vertical force acts on them. When the model was rolled to submerge the segment, the vertical force increased and the transverse force decreased since there was an upward buoyant force while the longitudinal force was unaffected. When the model was pitched with the bow down, the vertical load increased significantly as much as 23N with 3.4°, while the longitudinal load decreased. The horizontal load should not have been affected but in some cases, especially segment 3, they were more responsive than the longitudinal transducers. The coupling between motions may not have been completely removed, contributing to this discrepancy.

The transducers were least sensitive to heave. Only the vertical transducers were affected by heave and only the transducers of segment 3 were affected significantly. The largest single transducer response being 6N to a heave of 15mm.

The vertical load cells were the most sensitive to all the motions especially in segment 3 where 20N was measured in the vertical direction for a non-dimensional heave draft ratio of 0.043 (15 mm), 28N with a roll of 5.2° and 24N with a pitch of 1°. The values of heave, pitch and roll being the maximum values measured during previous testing. The response is not surprising considering that segment 3 has a weight of 150N. The calibration sheets for the test are available in Appendix I.1.

6.2 Open Water Towing Calibrations

Three tests, towing a fixed model the length of the basin (20m) at speeds of 0.19 m/s, 0.43 m/s and 0.64 m/s in open water were conducted to determine the hydrodynamic loads on the segment. The results in terms of individual transducer response at each speed is given in Table 6.2. As can be seen in most transducer positions the effects of hydrodynamic loading are negligible. Only certain transducers V11, V12, R21, H21, V25, R31, V32 and V34 are significantly affected and then only at the speeds of 0.43 and 0.64 m/s. H21 the transducer with the highest response measured an average force of 1.2N with a standard deviation of 0.6N at the highest test speed. Statistics for all the transducer measurements are given in Appendix I.2.

TABLE 6.1
EFFECT OF SHIP MOTIONS ON SEGMENT SUPPORT POINTS

TRANSDUCER POSITION	RATING N	HEAVE N/mm	PITCH N/deg	ROLL N/deg
R ₁₁	100	-	0.62	-0.10
H ₁₁	100	-	-1.00	-0.15
H ₁₂	100	-	.78	-0.32
V ₁₁	100	0.08	-1.79	-
V ₁₂	100	0.05	-1.55	-
V ₁₃	100	-	-1.27	0.12
RV ₁	140	-	.85	0.20
HV ₁	200	-	.99	0.06
R ₂₁	50	-	-	-
R ₂₂	140	-	-	-
H ₂₁	100	-	-	-0.12
H ₂₂	100	-	-	-0.16
H ₂₃	140	-	-	0.24
V ₂₁	100	0.22	-6.19	0.88
V ₂₂	100	0.12	-2.45	0.30
V ₂₃	100	0.30	-2.26	1.41
V ₂₅	200	-	2.32	-
R ₃₁	50	-	-	-
R ₃₂	140	-	-	-
H ₃₁	100	-	0.69	-0.42
H ₃₂	100	-	0.93	-0.38
H ₃₃	140	-	-0.77	0.10
V ₃₁	50	0.18	-4.91	0.06
V ₃₂	50	0.42	-7.72	1.77
V ₃₃	50	0.38	-6.46	1.29
V ₃₄	50	0.16	-3.24	0.61
V ₃₅	200	0.09	-3.26	0.27
V ₃₆	240	0.103	-2.26	0.47

"-" indicates the support point was not affected by the load
(less than 1N response for a roll of 10°, pitch of 3° or heave
of 15mm).

TABLE 6.2

TRANSDUCER RESPONSE DURING OPEN WATER TOWING TESTS

SPEED OF TEST m/s		0.19		0.43		0.64	
		AVE.	ST.DEV.	AVE.	ST.DEV.	AVE.	ST.DEV.
TOTAL MODEL RESISTANCE N		-8.8	69.8	-17.9	120.8	-32.6	174.2
TRANSDUCER POSITION	RATING N	TRANSDUCER RESPONSE N					
		AVE.	ST.DEV.	AVE.	ST.DEV.	AVE.	ST.DEV.
R ₁₁	100	0.1	0.1	0.2	0.1	0.2	0.1
H ₁₁	100	-0.2	0.1	-0.0	0.1	-0.2	0.2
H ₁₂	100	-0.4	0.1	-0.2	0.1	-0.4	0.2
V ₁₁	100	0.1	0.1	0.2	0.1	0.7	0.2
V ₁₂	100	0.1	0.1	0.4	0.1	1.1	0.2
V ₁₃	100	0.1	0.1	0.1	0.1	0.1	0.1
RV ₁	140	-0.0	0.1	0.2	0.1	0.6	0.1
HV ₁	200	0.3	0.1	0.1	0.1	0.3	0.1
R ₂₁	50	0.3	0.1	0.5	0.2	1.0	0.2
R ₂₂	140	0.1	0.1	0.0	0.0	0.1	0.1
H ₂₁	100	0.4	0.3	0.5	0.4	1.2	0.6
H ₂₂	100	-0.0	0.2	0.1	0.2	0.1	0.2
H ₂₃	140	-0.1	0.1	0.0	0.0	0.2	0.1
V ₂₁	100	0.2	0.2	0.2	0.2	0.4	0.3
V ₂₂	100	0.0	0.1	0.1	0.1	-0.0	0.1
V ₂₃	100	0.1	0.2	-0.0	0.2	0.0	0.2
V ₂₅	200	0.8	0.3	0.4	0.2	0.8	0.4
R ₃₁	50	-0.4	0.3	0.1	0.4	0.5	0.5
R ₃₂	140	-0.2	0.1	0.0	0.1	0.1	0.1
H ₃₁	100	0.2	0.2	0.1	0.3	0.2	0.4
H ₃₂	100	-0.2	0.1	-0.3	0.2	-0.4	0.2
H ₃₃	100	0.0	0.02	0.0	0.1	-0.0	0.1
V ₃₁	50	0.2	0.2	-0.1	0.3	-0.2	0.4
V ₃₂	50	-0.0	0.1	-0.4	0.1	-0.6	0.1
V ₃₃	50	-0.0	0.2	-0.2	0.4	-0.7	0.2
V ₃₄	50	0.2	0.2	-0.2	0.4	-0.7	0.2
V ₃₅	200	0.2	0.03	-0.01	0.1	0.0	0.1
V ₃₆	240	0.1	0.2	-0.1	0.2	0.0	0.1

7. ICE SHEET TESTS

7.1. Test Matrix

In total three ice sheets were grown to document segment response to ice loads and collect ice load data. The purpose of sheet #1 was to document the performance of segment 2 only, while in ice sheets #2 and #3 measurement from all three segments were recorded. Ice sheet #1 and #2 had thicknesses of 20-30 mm while ice sheet #3 had a thickness of 48mm. Ice flexural strength during the tests was between 20 and 50 KPa.

A log of the ice tests for all 3 ice sheets is given in Table 7.1. Below is a note of explanation on the types of different tests:

- New sheet (NS): a standard run with fixed model through an unbroken ice sheet.
- Channel widening (CW): towing the fixed model down the previously broken ice channel with the centreline of the model roughly in line with the edge of the channel. Since ice is broken on the segment side of the model, data on the behaviour of the segment can be collected.
- Segment scraping (SS): the model is held at a yaw angle of roughly 25° and moved down the ice channel so that the ice edge contacts segment 2 (the hull at stations 9.5 to 9).
- Ice Impact Tests (II): Two types of tests were performed on the segments with the model stationary. In the first test pieces of ice were pushed by hand against the segment at 4 to 6 locations during the instrumentation scanning time. In the second test hand held pieces of ice were dragged across the segment surface 4 to 6 times at different stations and waterlines.

The data acquisition system described in Chapter 3 was used to collect and store the measurements of the segment transducers, the model force block, and the model speed and position indicators. Scanning rate for the instrumentation was 30 Hz during ice sheet #1 and 60 Hz during ice sheets #2 and #3.

7.2 Test Procedures

Due to the high sensitivity and limited capacity of the load cells used to instrument each segment, extra precaution was taken during these ice tests. Such precaution, combined with rigid tests constraints such as the test length and time, have reduced the quantity of data that can be obtained during these tests. For standard resistance tests of the 20th scale model of the CCGS PIERRE RADISSON, it is usually possible to obtain three runs per ice sheet up to a maximum speed of 9 knots full scale. For the segmented model, only two runs per ice sheet up to a maximum speed of 4 knots were performed. The reduction in speed and number of tests should result in better quality data.

TABLE 7.1
ICE TESTS CONDUCTED

ICE SHEET	RUN	TYPE OF TEST	ICE THICKNESS mm	ICE STRENGTH kPa	MODEL SPEED m/s	FULL SCALE SPEED knots	LENGTH OF TEST RUN L/L_{WL}
1	NS2	NS	20	35	0.15	1.3	1.97
1	NS3	NS	20	35	0.43	3.7	2.19
1	CW1	CW	20	35	0.15	1.3	2.19
1	CW2	CW	20	35	0.45	3.9	3.28
1	CW3	CW	20	35	0.10	0.9	2.19
1	CW4	CW	20	35	0.60	5.2	2.19
1	SS1	SS	20	35	0.15	1.3	2.19
1	SS2	SS	20	35	0.45	3.9	2.19
1	DI1	II	-	-	-	-	-
1	DI2	II	-	-	-	-	-
2	S11	NS	27	25	0.14	1.2	1.54
2	S12	NS	27	25	0.45	3.9	2.65
2	CW5	CW	27	25	0.18	1.6	1.44
2	CW6	CW	27	25	0.45	3.9	2.85
2	CW7	CW	27	25	0.66	5.7	4.37
2	F11	II	-	-	-	-	-
2	F21	II	-	-	-	-	-
2	F31	II	-	-	-	-	-
2	D11	II	-	-	-	-	-
2	D21	II	-	-	-	-	-
2	D31	II	-	-	-	-	-
3	S31	NS	47	30	0.15	1.3	2.07
3	S32	NS	47	30	0.30	2.6	2.16
3	CW8	CW	49	30	0.10	0.9	1.75
3	CW9	CW	49	30	0.22	1.9	2.84

Note: $L_{WL} = 4.575$ m

A primary constraint which reduced the available basin length is acceleration and deceleration levels. Ordinarily for a resistance test, the total force measured by the force block during acceleration and deceleration intervals is as high as five to ten times the mean ice resistance. However, inertia forces acting on each segment are expected to be proportional to its mass and angular momentum characteristics. To minimize such effects on the load cells, the acceleration and deceleration lengths were increased to lower the maximum acceleration forces. For this reason, most high speed tests were performed following a lower speed test. The model between each test was backed to the beginning of the basin. The model was gradually accelerated to speed in the previously broken channel, eliminating any loss of basin length due to the slower acceleration.

The ice sheets were prepared in accordance with Arctec's standard procedures and the properties of ice were measured and reported using the procedures described in [1].

Following each of the three freezes, the ice sheet was allowed to slowly decay in strength while being monitored. The monitoring consisted of ice flexural strength tests that were performed at least every hour at six locations on the ice sheet - 3 on each side of the test basin. During this "come down" period, the segments were all washed with warm water to ensure that any ice build-up between segments would melt. Once it was certain that any build-up was eliminated and that all load cells were working, then the segments were adjusted and properly preloaded. As soon as the model was ready to test, the elastic modulus test described in Appendix E of [1] was performed. When the average ice strength reached approximately 25 kPa, the ice resistance tests were performed.

The model was fixed to the towing carriage so that no heave or roll or pitch of the model was possible. Sway was eliminated by attaching two wires to the model stern with the other end of each wire pulled taut around the towing carriage rail guides so that the wire ends of the wires move with the towing carriage. Before and after each ice sheet test series the ice thickness was measured at one metre intervals along the length of the basin. These values were then averaged to give the mean thickness for each test.

7.3 Results of Ice Impact Tests

While the model was in the basin several static tests were performed to see how the segment responded to ice impacting against it and ice travelling across it. A piece of ice was pushed against the segments at 4 to 6 selected points and ice was also dragged along the segment at selected waterlines and stations. The results are summarized in Tables 7.2 to 7.4. There was a high degree of inaccuracy in the tests as some of the stations and waterlines were not marked on the segment so their position had to be estimated. As well the person conducting the test could not see all parts of the segment, especially the bottom half and as the ice crushed against the segment it tended to slide - often not in the intended direction.

TABLE 7.2

ICE IMPACT TESTS ON SEGMENT 1

DESCRIPTION OF ICE POSITION	APPLIED x m	MEASURED x m	APPLIED z m	MEASURED z m
moving ice aft on the 23' WL (z = 0.027 m)	2.4 → 2.03	2.32 → 2.1	0.027 ± 0.01	0 - 0.1
moving ice forward on the 23' WL (z = 0.027 m)	2.03 → 2.4	2.10 → 2.40	0.027 ± 0.01	0.1 - 0
moving ice down at station 10 (x = 2.198)	2.198 ± 0.02	≈ 2.2	0 → 0.15	0.06
moving ice at station 10 (x = 2.198)	2.198 ± 0.02	2.2 to 2.29	0.15 → 0	0.055 → 0.041
pushing ice at 23' WL at station 10	2.20 ± .02	2.19	0.03 ± .01	0.06
pushing ice at 19.5' WL at station 10	2.20 ± .02	2.22 - 2.21	0.08 ± .02	.055
pushing ice at 23' LW at station 10.23	2.30 ± .03	2.34 - 2.31	0.03 ± .01	0

TABLE 7.3

SEGMENT 2: ICE IMPACT TESTS

DESCRIPTION OF ICE POSITION	APPLIED x m	MEASURED x m	APPLIED z m	MEASURED z m
station 9, 24' WL	1.76 ± .005	1.754 - 1.758	.03 ± .01	.022 - .025
station 9.25, 24'WL	1.88 ± .015 1.865 - 1.895	1.887 - 1.907	.03 ± .01	0.010
station 9.5, 24'WL	1.98 ± .005	1.972 - 1.993	.017 - .037	0.101 - .015
station 9, 19.5'WL	1.75 - 1.77	1.778 - 1.781	.065 - .095	0.136 - 0.141
station 9.25, 19.5'WL	1.860-1.900	1.886 - 1.897	.065 - .095	0.115 - 0.123
station 9.5, 19.5'WL	1.97 - 1.98	1.979 - 2.018	.065 - .095	0.093 - 0.107
moving aft on the 23' WL	2.02 → 1.62	1.92 → 1.63	.017 - .037	.017 → .072
moving forward on the 23' WL	1.62 → 2.02	1.62 → 1.98	.017 - .037	.07 → .038
moving down at station 9.25	1.86 - 1.900	1.930 - 1.905	0.00 → 0.15	.011 → .150
moving up at station 9.25	1.86 - 1.900	1.891 - 1.953	0.00 → 0.15	.150 → .011
From station 9.5 on the 23' WL moving down and aft to Station 9 on the 19.5' WL	1.98 → 1.76	2.020 → 1.784	.021 → 0.08	.011 → .150
From station 9.5 on the 19.5' WL moving up and aft to Station 9, 23' WL	1.76 → 1.98	1.708 → 1.937	.08 → .027	.112 → .011

TABLE 7.4

ICE IMPACT TESTS ON SEGMENT 3

DESCRIPTION OF ICE POSITION	APPLIED x m	MEASURED x m	APPLIED z m	MEASURED z m
moving ice aft on 23' WL	1.62 → .89	1.59 → .89	0.03 ± .01	0.00 → 0.43
moving forward on the 23' WL	0.89 → 1.62	.89 → 1.61	0.03 ± .01	0.02 - 0.04
move ice down at station 8	1.32 → .01	1.26 - 1.32	0 → 0.15	0.00 → 0.13
move ice up at station 8	1.32 ± .01	1.35 → 1.31 → 0.15 → 0		0.15 → 0
pushing ice against segment at 23' WL station 7.5	1.10 ± .02	0.9	0.03 ± .02	0.04
pushing ice against segment at 19.5' WL station 7.5	1.10 ± .02	.89 - 1.08	0.08 ± .92	0.09 - 0.12
pushing ice against segment at 23' WL station 8.5	1.54 ± .02	1.58 - 1.52	0.03 ± .02	.01
pushing ice against segment at 19.5' WL station 8.5	1.54 ± 0.02	1.49 - 1.60	0.08 ± .02	.06 → .09

7.4 Transducers Lift Off and Zero Offsets

In the first phase of this project, relatively flexible supports were used to hold the segments in the model. It was found that these supports allowed the segments to move slightly under the action of the ice forces so that at the end of a test run instead of returning to a zero reading some transducers would measure net load or offset. This would invalidate results from the transducer since it is not possible to determine when the extra load had been applied. The loads have been labelled zero offsets.

Another problem was that some of the transducers would not receive an adequate preload and the segment would loose contact with the transducers. In this case the transducer would not be able to measure any loads. This problem has been labelled segment lift off.

The tension links were put in place to overcome these two difficulties and the results from tests of segment 2, ice sheet #1 and segments 1, 2 and 3 in ice sheet #2 have been examined to determine the success of the tension links. Definitely, segment lift off is no longer occurring. All the transducers can be preloaded properly and they do not lift off during testing.

Zero offsets from ice sheet #1 for 3 runs have been calculated using the test time histories. Transducer readings at the end of the test run were compared to the readings at the beginning of the test run and the zero offsets of each transducer was calculated for each of 3 runs. The transducer offsets are given in Table 7.5.

Zero offsets for 3 runs from ice sheet #2 were determined by comparing the initial zero reading of two consecutive runs. This is a stiff test since usually 3-5 minutes elapse between tests in which time the model is moved back down to the end of the basin. Thus more model movement has occurred that could cause the segment to offset slightly. Also in some tests the model was moved slightly along the towing carriage. The offsets are reported in Table 7.6.

In both Table 7.5 and 7.6 the zero offsets have been compared to the offsets of three test runs from Phase I having a similar speed and ice thickness. Not all transducers presently in the model existed during Phase I so these readings are indicated as a dash.

From Table 7.5 it is seen that in general through the improved segment support all of the transducers remain in contact during the tests. Previously in the three test runs used for comparison - either R_{21} or H_{21} would loose contact. Since at least one measurement is needed in each direction to resolve the position of the force this was not possible in the cases where R_{21} lost contact. Now that the loss of contact has been corrected through use of the tension links all of the data is available for analysis. R_{21} and H_{21} had offsets greater than 3% of their rating during one test each.

TABLE 7.5

ZERO OFFSETS OF SEGMENT 2, ICE SHEET #1
 COMPARED TO ZERO OFFSETS FROM PHASE I TESTING (from [1])

ICE SHEET RUN	Phase II: Current Results				Phase I (from [1])		TRANSDUCER RATING N
	1 NS2	1 NS3	1 CW2	1 1	1 2	2 1	
ICE THICKNESS SPEED (m/s)	.15	.41	.41	25	25	25	
R ₂₁ (N)	G	F	G	NL	NL	G	50
R ₂₂ (N)	G	G	G	-	-	-	140
H ₂₁	F	G	E	E	E	N.L.	100
H ₂₂	G	G	E	E	E	P	100
H ₂₃	G	E	E	-	-	-	140
V ₂₁	G	G	E	G	G	G	100
V ₂₂	G	E	E	G	G	G	100
V ₂₃	G	E	E	G	G	G	100
V ₂₄	F	G	E	G	G	G	50
V ₂₅	E	E	E	-	-	-	200

Legend:

N.L. = Not loaded

P = Poor signal, zero offset <3.0% of Rated Capacity (<3.0N for a 100N cell)

F = Fair signal, large offset <3.0% of Rated Capacity (<3.0N for a 100N cell)

G = Good signal, small offset <1.5% of Rated Capacity (<1.5N for a 100 N cell)

E = Excellent signal, negligible offset <.5% of Rated Capacity (<.5N for a 100N cell)

TABLE 7.6

ZERO OFFSETS DURING ICE SHEET #2
COMPARED TO ZERO OFFSETS FROM PHASE I TESTING (from [1])

PHASE II: Current Results				PHASE I (from [1])			TRANSDUCER RATING
SPEED	.45	.14	.64	.14	.33	.58	
TYPE OF TEST	CHANNEL WIDENING	NEW SHEET	CHANNEL WIDENING	TEST 1 RUN 1	TEST 2 RUN 1	TEST 2 RUN 2	
Offsets N							
R ₁₁	E	G	E	G	P	F	100
H ₁₁	E	G	E	N.L.	N.L.	N.L.	100
H ₁₂	E	F	E	N.L.	N.L.	G	100
V ₁₁	E	G	E	G	G	G	100
V ₁₂	E	E	G	G	G	G	100
V ₁₃	E	P	G	-	-	-	100
RV ₁	E	G	G	-	-	-	140
HV ₁	E	E	G	-	-	-	200
R ₂₁	G	G	P	N.L.	G	G	50
R ₂₂	E	E	E	-	-	-	140
H ₂₁	E	F	F	E	N.L.	N.L.	100
H ₂₂	E	E	G	E	P	F	100
H ₂₃	E	G	E	-	-	-	140
V ₂₁	E	E	G	G	G	G	100
V ₂₂	E	F	F	G	G	G	100
V ₂₃	E	E	E	G	G	G	100
V ₂₅	E	E	E	-	-	-	200
R ₃₁	E	P	F	G	G	G	50
R ₃₂	E	E	E	-	-	-	140
H ₃₁	E	G	F	F	F	F	100
H ₃₂	E	E	F	G	F	F	100
H ₃₃	E	G	P	-	-	-	140
V ₃₁	G	G	E	G	G	G	50
V ₃₂	E	E	F	G	G	G	50
V ₃₃	G	G	F	G	G	G	50
V ₃₄	E	E	F	N.L.	G	G	50
V ₃₅	E	E	E	-	-	-	200
V ₃₆	E	E	E	-	-	-	240

LEGEND:

N.L. = Not loaded

P = Poor signal, zero offset >3.0% of Rated Capacity (>3.0N for a 100 N cell)

F = Fair signal, zero offset <3.0% of Rated Capacity (<3.0N for a 100 N cell)

G = Good signal, small offset <1.5% of Rated Capacity (<1.5N for a 100 N cell)

E = Excellent signal, negligible offset <.5% of Rated Capacity (<.5N for a 100 N cell)

There was also zero offsets occurring on transducers V_{21} and V_{24} during one test. The other transducers were all either good (offsets less than 1.5% of their rating) or excellent (offsets less than .5% of their rating during the ice test. Because V_{21} and V_{24} are so close together the slightest movement of the segment shifts the load from one onto the other increasing the offset of each. An attempt to eliminate this was made by removing transducer V_{24} during ice sheets #2 and #3.

In Table 7.6 the offsets from ice sheet #2 are presented. The segments still had offsets - usually in the longitudinal direction where segment performance is poor anyhow or in the transverse direction where most of the load is acting.

Segment 1 performed the best. Previously one to two transducers on this model could not even maintain contact. Now with the addition of a third vertical load cell preloading it is the easiest of all the three segments. On one run at the highest speed no offsets occurred. On the other two runs examined, V_{13} had offsets of 1.3 and 3.5N, R_{11} had one offset of 1.1N and H_{12} had an offset of 1.7N.

R_{21} a longitudinal transducer on Segment 2 had poor response on one out of three runs. Also on two out of 3 runs H_{21} and V_{22} had poor response. Only one of the offsets, 2.8N on H_{21} , exceeded 2N. It appears that removing the load cell from the V_{24} position increased the vertical offsets, on Segment 2 but not drastically. In comparison to the three runs from Phase 1 there were 4.5 times as many excellent responses on equal numbers of transducers.

Segment 3 behaved very well on two of the runs and poorly on another. R_{31} was offset at the end of two out of three runs. This is probably the same problem which caused poor performance of this load cell during the calibrations. Friction between the horizontal and vertical load cells and their bearing surfaces prevents the segment from returning to its zero position. This is especially true in the x direction where friction can occur at 6 load cells.

The load cells on Segment 3 also always indicated an offset in the horizontal direction in 2 out of 3 tests although in one case the net horizontal offset was zero and in neither of the other two cases did it exceed 2 Newtons. Considering that these load cells are the most highly loaded of any on the model it is where one would expect to look first for zero offsets.

Only during one run did offsets greater than 0.5N occur on any of the vertical cells of Segment 3 and for this run the net vertical offset was zero.

In the test result examined from Phase 1 no excellent responses were recorded. While on the current results 57% of the transducers had excellent response.

7.5 Ice Data from Sheet #1, #2, #3: Segment Forces and Locations

The magnitude of the normal force, the magnitude of the friction force and the location of the forces was determined by the computer algorithm for all of the test runs. For the entire scan time of each run two points of the transducer time histories were sampled every 0.5 seconds. The two points were averaged together to determine the reading of each transducer and these readings were used to find the forces and their locations on the segments from the algorithms described in Chapter 3. The results were graphed for each segment. Five plots per segment were produced. The first plot shows the normal force and friction force superimposed; the second the x position of the force where the graph limits correspond to the segment edges; the third the z position, which has been plotted as negative values so that the plot will have the same orientation as the segment rather than a flipped vertical orientation; the friction direction which is the counterclockwise angle from the horizontal of the friction force vector (i.e. at -90° is the friction force is acting down, at 0 it is acting aft, at 90° it is acting up, and at 180° or -180° it is acting forward); and the fifth plot shows the ratio of the friction force to the normal force. Typical plots - segment 2 from test S12 are shown in Figure 7.1. The complete set of plots for ice sheets #2 and #3 are available in Appendix J.2 and J.3.

Because the segments are unable to determine the locations of the forces when the total force has fallen below a certain minimum, the x, z, friction direction, friction force and friction ratio values have only been plotted when the total force exceeds 5N on segment 1, 8N on segment 2 and 12N on segment 3. When the total force falls below these cutoffs a null value is recorded for the x, z, friction force, friction ratio, and the friction direction values. This is why the plots are discontinuous. Null values were also used if the force position algorithm calculated the force to be outside the edges of the segment. A value of normal force equal to .96 of the total force was used when the position could not be determined. This corresponds to a friction ratio of 0.3. If the actual friction coefficient was .1 this would only result in less than a 4% error.

8N was chosen as the cutoff force during the first ice sheet when only segment 2 was instrumented. It was found that when the position of forces less than 8N was calculated, unreasonably high friction coefficients were found and forces were predicted to be off of the segment. Most of these 'garbage' results were removed when the 8N cutoff was introduced on segment 2. 8N reflects the errors found during calibration of segment 2. 5N for segment 1 and 12N for segment 3 were derived as well from examination of the test results.

The cut off force may in fact be a weak function of the segment weight since Segment 3 weighs 2 1/2 times more than segment 2. Segment 1 is one third the weight of segment 2.

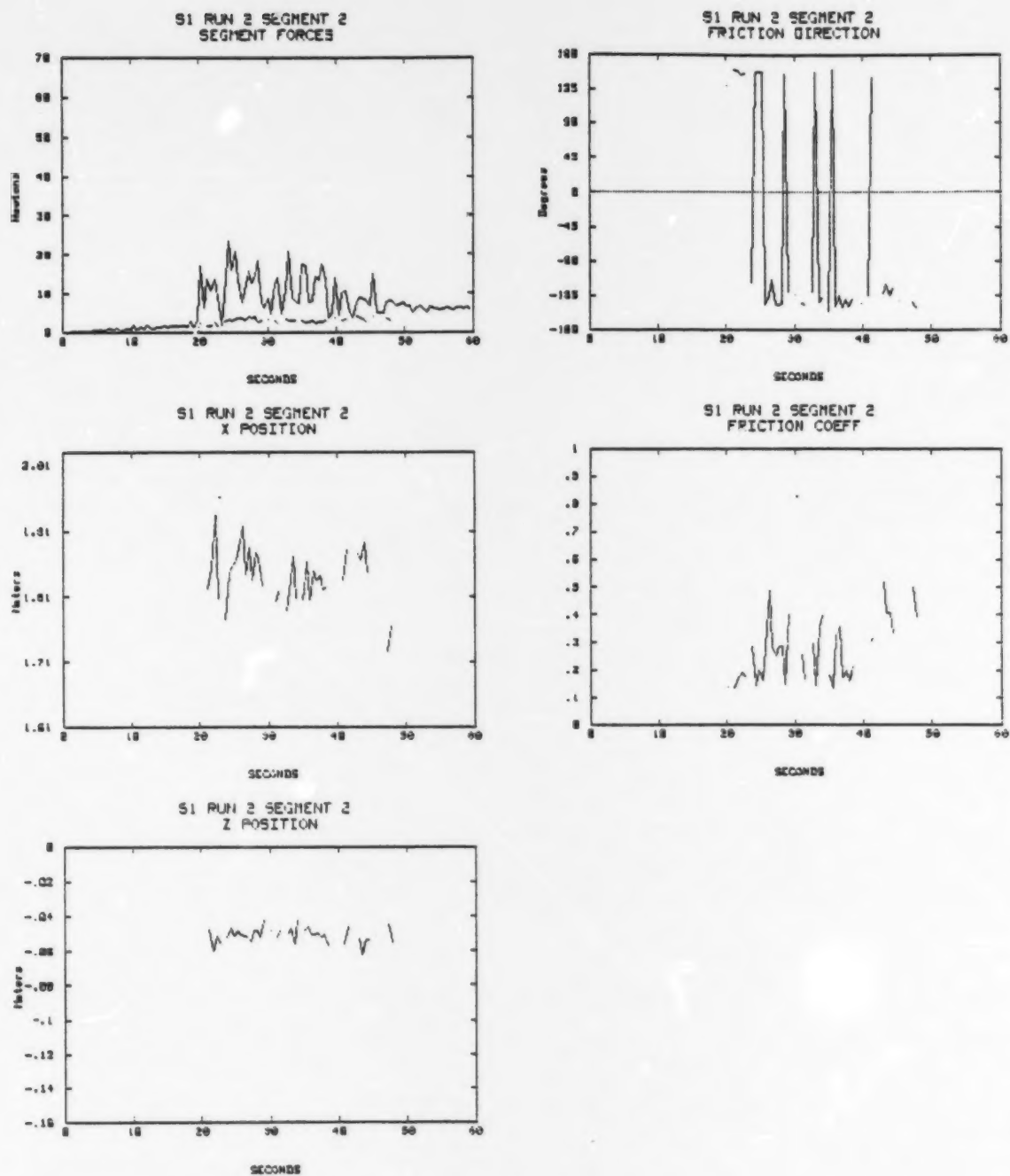


FIGURE 7.1
TYPICAL PLOTS OF ICE LOAD ANALYSIS
($h = 27 \text{ mm}$, $V = .45 \text{ m/s}$ $\sigma_f = 25 \text{ kPa}$)

8.0 ANALYSIS OF ICE TEST DATA

8.1 Analysis of Time History Statistics

From examination of the ice force and location statistics presented in Tables 8.1 and 8.2 some general observation can be made about the normal forces, and their location on the hull.

The first observation is that the channel widening tests (indicated by a CW label) and the level ice runs (indicated by a S1 or S3 label) of the same speed have virtually the same average normal force. As well the other parameters are in reasonable agreement between the two tests. So for the purposes of this analysis the two types of tests have been considered as equivalent.

It can be seen that the average normal force increases from segment 1 to segment 3. By dividing the average normal force on each segment by the segment length at the test waterline an average force per unit length can be found for each segment. In Figures 8.1a and 8.2b the results have been plotted for each ice sheet (5 tests in ice sheet #2 and 4 tests in ice sheet #3). For ice sheet #2 which had a thickness of 27 mm and a flexural strength of 25 kPa the normal force on each segment is exponentially increasing with speed. As well the force increases with segment number and the difference between the segments widens with speed. It can be seen that for ice sheet #3 with a thickness of 48 mm the increases are much sharper. At a speed of 0.30 m/s the forces on segment 3 have tripled with the increase in thickness, while on segment 1 and 2 they have roughly doubled. Also of note is that in Figure 8.1a the data points of segment 2 follow closely those of segment 3 while in the data from the thicker ice (Figure 8.1b) segment 2 data lies closer to those of segment 1 than of segment 3. In thinner ice with smaller cusps it is quite likely that turning and sliding of the ice pieces is occurring on segment 2 while in the thicker ice with a larger cusp length this action has been delayed until segment 3.

The average position of the ice forces was fairly consistent between different model speeds and ice thicknesses. On segment 1, the force tends to act at 2.23 m which is just forward of station 10 and the standard deviation of the force from the average position is low between 0.03 - 0.09 m for all the tests. On segment 2 the forces are centered at 1.84 m which is aft of station 9.25 (1.87 m) and 0.08 m forward of the location of the normal force anticipated in [1]. The location 1.84 m is also the center of the segment. The deviation from the average position on segment 2 ranges from 0.04 to 0.10 m. On segment 3 the force is located on average at 1.21 m to 1.32 m depending on the test. These values are near the center of the segment 1.25 m. There is more variation in average position than that seen on segments 1 and 2 and the standard deviation of the position changes from 0.13 to 0.24 m.

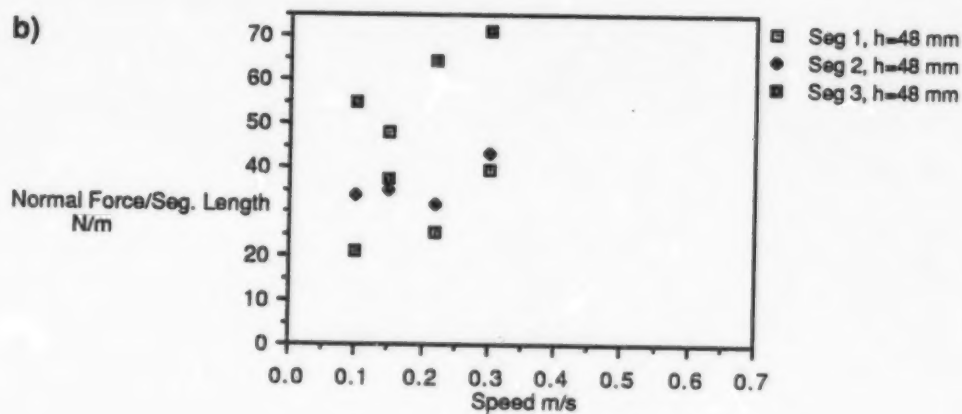
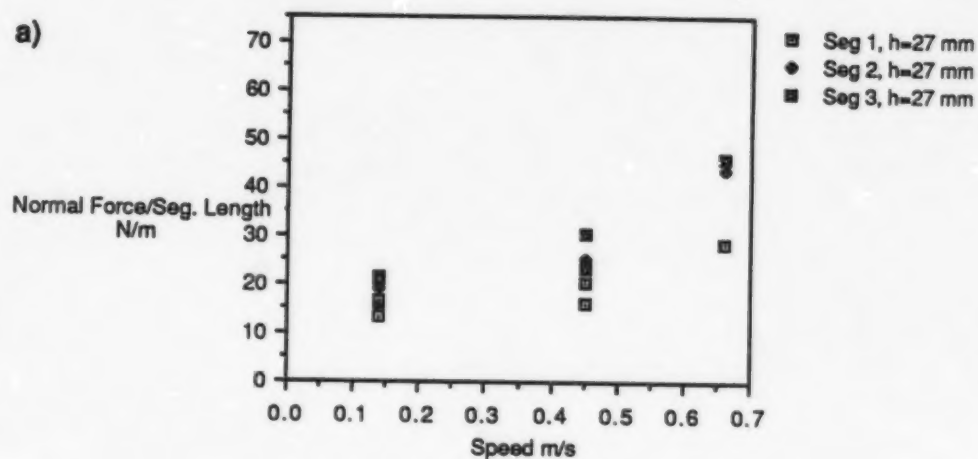


Figure 8.1
Normal Force per Unit Segment Length; a) h=27 mm; b) h=48 mm

(h = ice thickness)

TABLE 8.1

SUMMARY OF SEGMENT FORCES AND LOCATION
FROM ENTIRE RUN WITH SAMPLES TAKEN EVERY 0.5 SECONDS

TEST AND RUN TYPE OF TEST	SI-1 NEW SHEET RUN 1		SI-2 NEW SHEET RUN 2		CW-5 CHANNEL WIDENING		CW-6 CHANNEL WIDENING		CW-7 CHANNEL WIDENING	
SPEED (m/s)	.14		.45		.14		.45		.66	
	AVE.	STD. DEV.	AVE.	STD. DEV.	AVE.	STD. DEV.	AVE.	STD. DEV.	AVE.	STD. DEV.
SEGMENT 1										
Normal Force (N)	5.5	1.7	5.4	2.1	4.5	1.7	6.8	2.7	9.6	4.2
x position (m)	2.26	0.09	2.23	.04	2.22	0.08	2.20	0.03	2.22	0.06
z position (m)	0.04	0.01	0.04	0.004	0.04	0.01	1.04	0.004	0.03	0.01
Friction Coeff.	.55	.20	.38	.14	.39	.23	.27	.15	.56	.26
Friction Dir.(deg)	-97	17	-97	58	-51	110	-124	8	-115	7
Data Points	30		22		17		42		39	
SEGMENT 2										
Normal Force (N)	4.5	2.5	10.9	4.9	6.8	3.1	11.2	5.4	19.5	8.3
x position (m)	1.81	.04	1.84	.04	1.84	.08	1.83	.04	1.83	.05
z position (m)	.03	.01	.05	.00	.05	.01	.06	.004	.06	.01
Friction Coeff.	.12	.08	.21	.11	.11	.04	.11	.06	.19	.11
Friction Dir.(deg)	29	51	-53	134	-58	84	-86	42	-62	35
Data Points	9		38		31		40		46	
SEGMENT 3										
Normal Force (N)	16.0	10.3	17.6	8.9	16.1	8.9	23.0	7.9	34.8	14.3
x position (m)	1.3	.13	1.25	.24	1.21	.13	1.25	.18	1.32	.17
z position (m)	.04	.01	.03	.01	.05	.01	.04	.01	.04	.01
Friction Coeff.	.17	.06	.27	.19	.11	.04	.18	.09	.26	.12
Friction Dir.(deg)	-30	16	-70	29	-58	23	-68	22	-74	16
Data Points	22		17		45		44		40	
Time of Active Run (sec)	19-60		21 - 45		25 - 60		25 - 54		20 - 45	

Ice thickness = 27 mm

Ice strength = 25 KPa

TABLE 8.2

SUMMARY OF SEGMENT FORCES AND LOCATIONS
OVER THE ICEBREAKING SECTION OF THE TEST RUN
WITH SAMPLES TAKEN OVER 0.5 SECONDS

TEST AND RUN TYPE OF TEST	S3-1 NEW SHEET		S3-2 NEW SHEET		CW-8 CHANNEL WIDENING		CW-9 CHANNEL WIDENING	
SPEED (m/s)	.15	.01	.30	.01	.10	.01	.22	.01
	AVE.	STD. DEV.	AVE.	STD. DEV.	AVE.	STD. DEV.	AVE.	STD. DEV.
SEGMENT 1								
Normal Force (N)	16.1	7.3	13.2	6.2	7.1	4.2	8.4	5.0
x position (m)	2.27	.06	2.26	.06	2.24	.04	2.24	.04
z position (m)	.05	.01	.05	.01	.06	.01	.05	.01
Friction Coeff.	.48	.64	.44	.17	2.2	3.4	2.09	5.00
Friction Dir.(deg)	-2	121	-31	120	74	30	67	58
Data Points	81		36		101		67	
SEGMENT 2								
Normal Force (N)	15.6	12.3	19.3	12.0	15.0	13.4	14.2	10.2
x position (m)	1.90	.11	1.84	.09	1.84	0.10	1.86	.08
z position (m)	.06	.02	.05	.02	.07	.03	.05	.02
Friction Coeff.	.30	.16	.25	.11	.22	.10	.21	.10
Friction Dir.(deg)	-93	12	-87	36	-99	17	-88	17
Data Points	96		49		90		73	
SEGMENT 3								
Normal Force (N)	28.5	34.7	53.8	38.6	41.6	45.3	49.0	37.2
x position (m)	1.26	.19	1.24	.17	1.26	.18	1.26	.15
z position (m)	.06	.03	.06	.02	.07	.02	.06	.02
Friction Coeff.	.37	.20	.17	.12	.14	.10	.16	.11
Friction Dir.(deg)	-77	13	-75	26	-76	23.6	-80	19
Data Points	28		38		88		89	
Time of Active Run (sec)	Start 33	Stop 37	Start 25	Stop 58	Start 35	Stop 101.5	Start 25	Stop 84

Ice Thickness = 48 mm

Ice Strength = 30 KPa

The vertical position of the normal force in general seems to increase downwards with increasing segment number and increasing ice thickness. From segment 1 to segment 3 the largest increase in vertical position is 1.5 cm and the increase due to ice thickness increase of 20 mm was 0.5 to 1 cm. Roughly the forces seem to act about one half ice thickness below the waterline.

From examination of the average friction coefficients presented in Table 8.1 and 8.2 several observations can be made. The average friction coefficients on segment 1 seem to be excessively high. It was expected that the friction coefficient of ice on the hull would be in the range of 0.1 to 0.2. For the most part this is the case on segments 2 and 3. If the friction coefficient plots in Appendices J.2 and J.3 are examined, it can be seen that a typical plot for segment 1 has most values around 0.2 with peaks which rise above 1.0. These peaks raise the average value to the numbers given in Table 8.1 and 8.2. There are several possible reasons for this. Firstly when the position of the force was examined it was found that for many of the time history data points the force was occurring at or very near the stem. Secondly, the hull angles are changing very rapidly on segment 1 - particularly near the stem which reduces the accuracy of the hull interpolation and the segment has a concavity at the stem which is not present in the lines plan. Thus the angles predicted by the hull interpolation routine could be in error by as much as 5° as a result of the combination of these two errors. Errors in the hull angle cause error in the normals and thus errors in the normal force and friction force. To correct this error the offsets of segment 1 would have to be measured from the segment itself and 5 to 6 points on the segment per waterline would have to be used by the hull interpolation routine versus the 2 to 3 points used presently. Thirdly, the low force encountered by this segment causes a high error in resolving the friction force. For a force of 5N and a friction coefficient of 0.2 the friction force would be 1N which is approaching the limits of accuracy of the segment transducers. For these reasons the friction coefficient and the friction direction on segment 1 have not been included in the discussion of the ice data.

With regard to the friction coefficient on the other two segments, the measured values agree reasonably well with the expected values. For segment 2 the friction coefficients and their variation are considerably larger in the thicker ice than in the thinner - roughly .24 versus 0.15.

The friction direction angle ψ decreases from segment 2 to segment 3. The friction seems to act principally in the downward direction rather than in the water plane. In fact in some cases the friction vector is pointing slightly forward. A friction vector which acts forward does not agree with intuition or with theory [4]. The question as to why these values are predicted by the force position algorithm remains unresolved. Further investigation will be necessary to study the friction phenomenon in more detail perhaps with the aid of underwater video to observe the movement of broken ice relative to the hull.

8.2 Analysis of Time History Peaks

A more in-depth analysis of the data collected was conducted on tests CW5, CW9 and S32. CW9 and S32 were analyzed to compare two tests at the same ice thickness. Although CW5 had a test speed of 0.14 m/s, it was closest in speed to that of CW9 which had a speed of 0.22 m/s, and so these two tests were used to compare two tests at similar speeds but different ice thicknesses.

From each test a 30 second portion of the time history was chosen. On each 30 second portion, three consecutive measurements of each transducer were averaged together starting at every 6th measurement of the time history. These averaged transducer measurements were used in the data reduction algorithm. The results were values for F_n , x , z , α , β , μ and ψ at each one-tenth second of the test time history, which were stored on a mass storage device.

The normal force values were plotted on the computer screen for each segment and using a cursor the points in time at which the normal force maxima occurred were selected. Figure 8.2 is a normal force plot with the selected points indicated by a vertical line through them. Knowing where the maxima occur in the time history the x , z , α , β , μ and ψ values at the maxima can be retrieved from the data set. In Appendix K the maximum values of each segment for each of the three tests are listed in table form. The mean values of each of the seven parameters were also computed and are given in Table 8.3. As well the normal force was plotted as the dependent variable against x , z , α , β , μ , and ψ so that any trends in the maxima could be detected.

Referring to Table 8.3 it can be seen that there does not appear to be a correlation between the average longitudinal position of the maximum normal forces and the ice thickness or model speed. Except in the case of segment 3 where the position of the force is moving aft as the speed and thickness increase. The average longitudinal position of the maximum forces coincides quite closely with the average normal force position of the entire time history.

In Figures 8.3 to 8.5 the longitudinal position of the peak force has been plotted for all segments of each test. It can be seen that in general over the length of the segmented section of the model the peak normal force is increasing exponentially from segment 1 to segment 3 with the normal force on segment 3 being about 5 times that on segment 1.

The absence of data points at the aft ends of segments 2 and 3 indicates that these segment could be centering the forces when two separate forces are applied at each end of the segments. However, this hypothesis could not be confirmed or negated based on available observations.

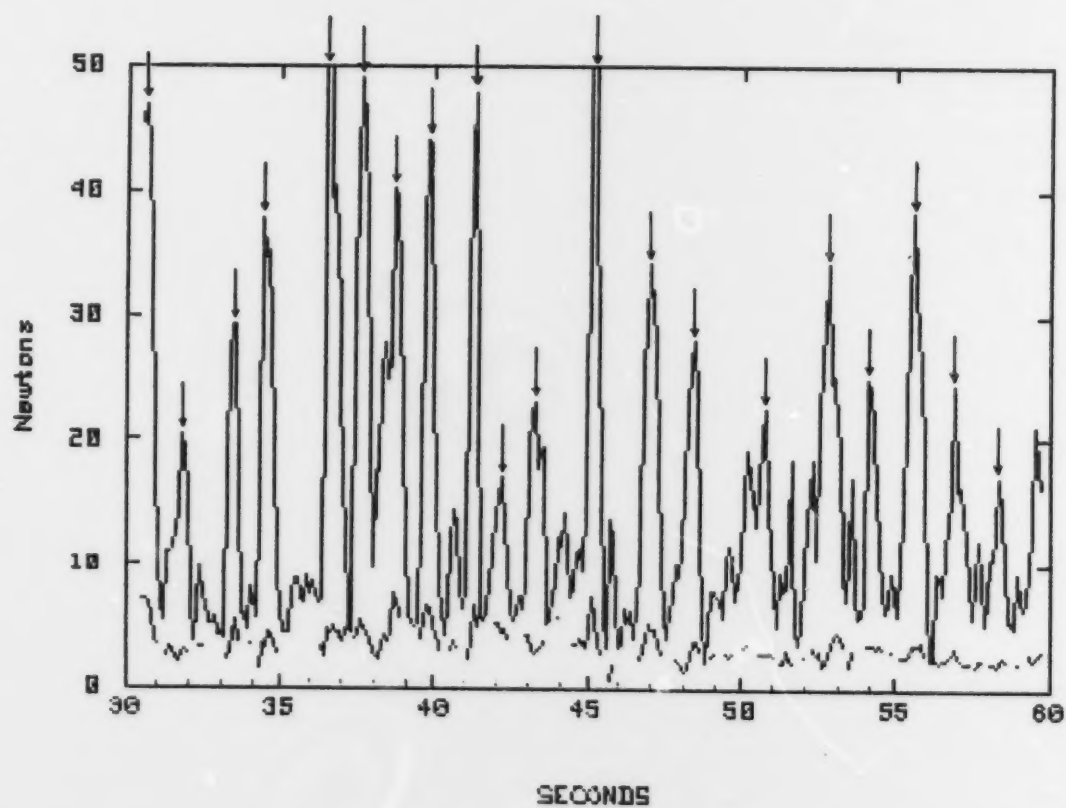


Figure 8.2 SELECTED NORMAL FORCE MAXIMA OF SEGMENT 2 TEST CW9

TABLE 8.3

MEAN OF FORCE PARAMETERS AT TIME HISTORY MAXIMA

Speed m/s	0.14	0.22	0.30
Thickness mm	27	48	48
Flexural Strength KPa	25	30	30
TEST	CW5 avg.	CW9 avg.	S32 avg.
SEGMENT 1:			
F _n	7.6	19.7	22.3
x	2.17	2.19	2.23
z	0.043	.047	.046
α	30	29	28
β	56	54	45
μ	.31	.15	.35
ψ	-83	31	-66
SEGMENT 2:			
F _n	12.6	34	38.1
x	1.83	1.84	1.84
z	.052	.042	.045
α	26	26	26
β	40	39	40
μ	.08	.14	.15
ψ	-83	-106	-100
SEGMENT 3:			
F _n	28.8	102	100
x	1.28	1.31	1.23
z	.050	.055	.062
α	9	10	9
β	16	17	16
μ	.10	.10	.10
ψ	-59	-85	-74

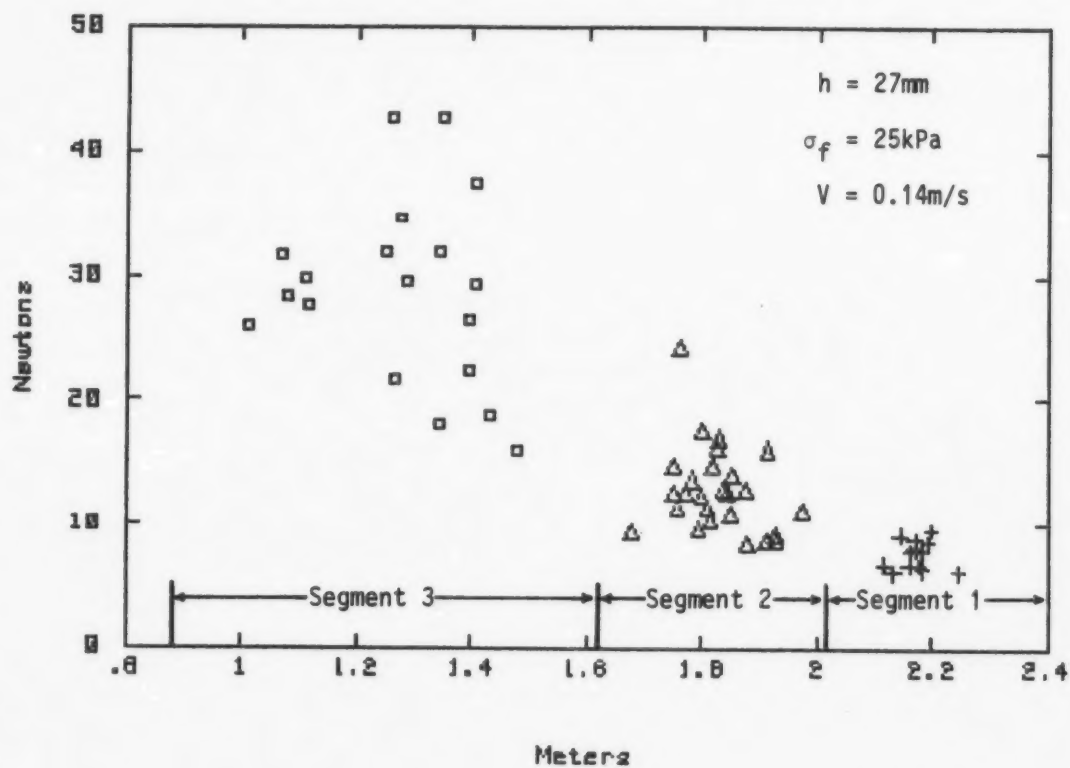


Figure 8.3 Longitudinal Position of Maximum Normal Forces During Test CW5

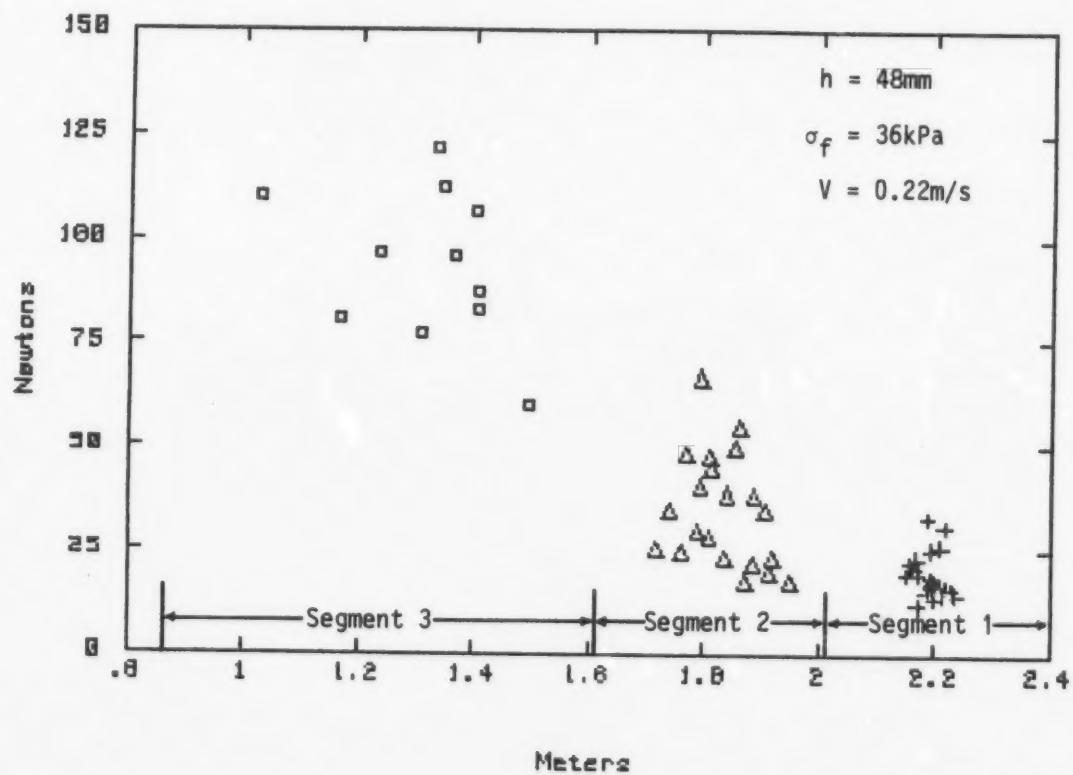


Figure 8.4 Longitudinal Position of Maximum Normal Forces During Test CW9

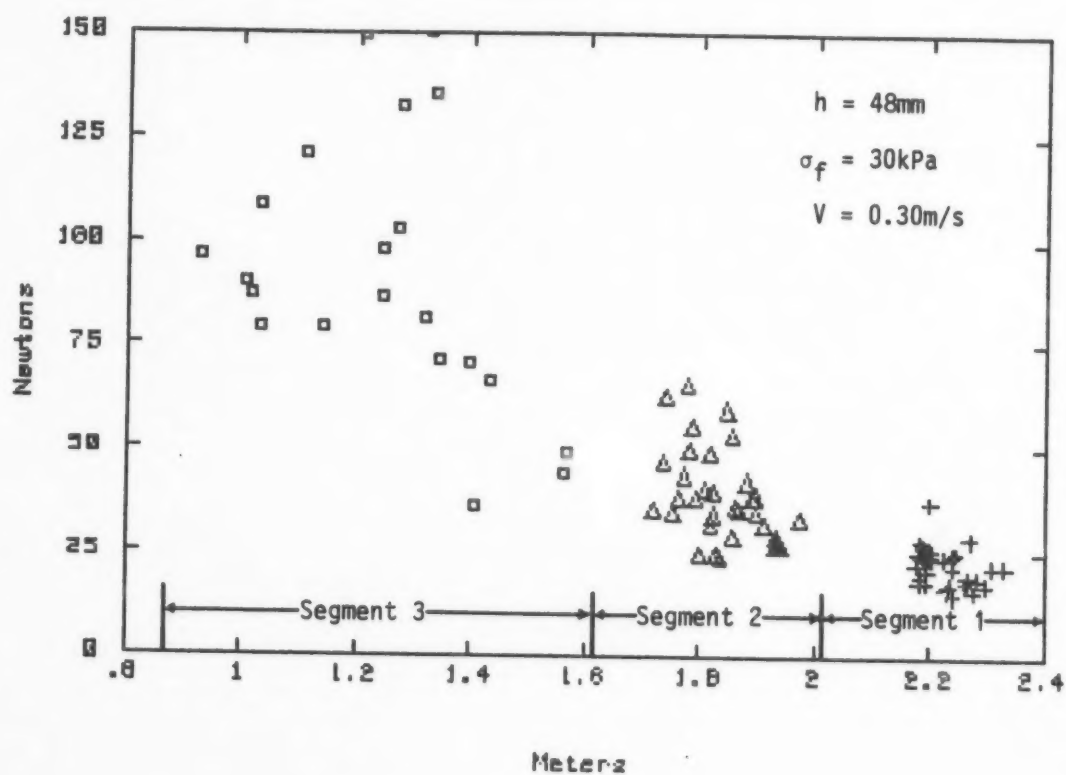


Figure 8.5 Longitudinal Position of Maximum Normal Forces During Test S32

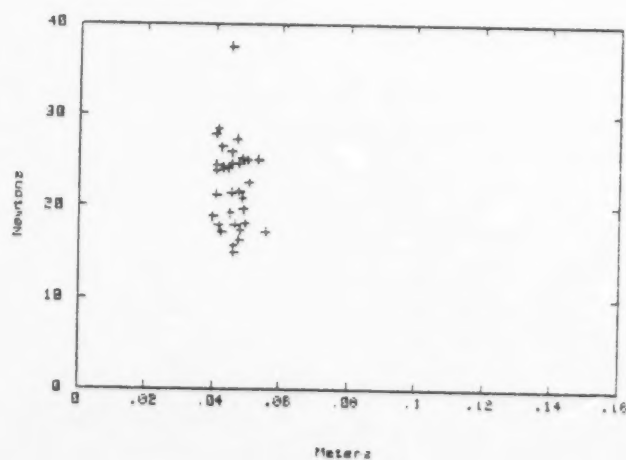


Figure 8.6 Vertical Position of the Maximum Forces on Segment 1 for Test S32
 ($h = 48\text{mm}$; $V = 0.30\text{m/s}$; $\sigma_f = 30\text{kPa}$)

The plots are quite revealing. Distinct upper and lower boundaries can be seen. As well it is quite easy to visualize a polynomial regression curve which would fit the data and would describe peak normal forces along the hull.

At the aft end of segment 3, α is already quite small, 3° . It is not known whether the force would continue to increase or hold constant aft of segment 3. Therefore, the division of segment 3 into 2 separate segments, or the creation of a fourth segment could reveal further information about the nature of the ice forces in the parallel midbody.

In general the vertical position of the maximum normal force does not exhibit a large amount of deviation however there are some trends in the vertical position which can be observed. For the ice thickness of 48 mm, the ice forces on segments 1 and 2 act at approximately one half the ice thickness below the waterline. The position of the maximum force is 10 to 15 mm lower on segment 3. The conclusion is that the lower center of action indicates a change from icebreaking forces to turning and friction forces. It can also be noted that in the thinner ice the drop in the vertical center of action occurs on both segments 2 and 3. This seems to indicate that turning and sliding occurred earlier in the thinner ice.

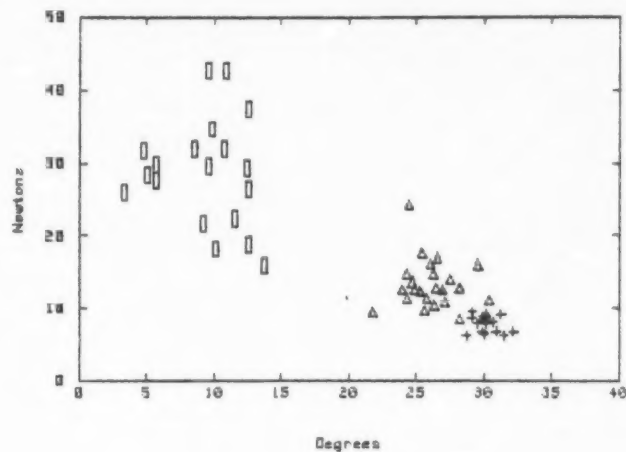
There did not seem to be any trend between magnitude of the normal force and vertical position of the force as shown in Figure 8.6. This plot shows the peak normal force plotted against vertical position for segment 1 during a test at $h = 48$ mm, $v = 0.30$ m/s.

The scatter of the vertical position is quite low. Generally the standard deviations were 1 cm or less. As well the average vertical position of the peak forces coincides with the average vertical position of the entire time history.

As can be seen in Table 8.3 in general the average hull angles at which the peak forces occur do not change with speed or ice thickness. However in viewing Figures 8.7 and 8.8 it can be seen that as both these angles decrease the peak normal force increases although the trend is more sharply defined for the waterplane angle. Figure 8.7 bears a strong resemblance to Figures 8.3 to 8.5 which is obvious since α decreases as one moves aft along a waterline. Again a curve describing the increase could be found through a polynomial regression of the data points.

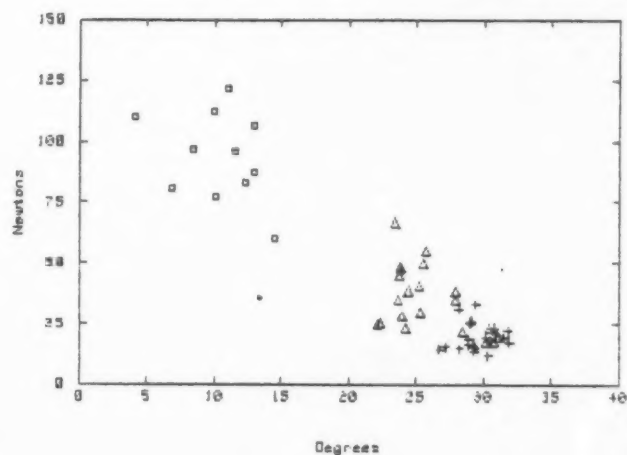
The data does not support the assumption that the normal force is proportional to the cosine of the waterplane angles. While there is general agreement in trend the magnitudes are vastly different. Using Test S32 as an example, at a waterplane angle of 30 degrees the normal force ranges from 15 to 35N while at a waterplane angle of 5° the normal force has values between 80 and 110N. This is a ratio of about 4 on the average while the cosine proportion would indicate a ratio of 1.15.

a)



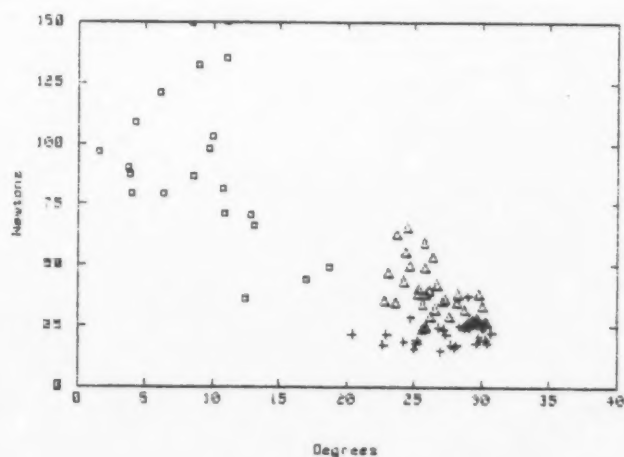
$h = 27\text{mm}$
 $\sigma_f = 25\text{kPa}$
 $V = 0.14\text{m/s}$

b)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0.22\text{m/s}$

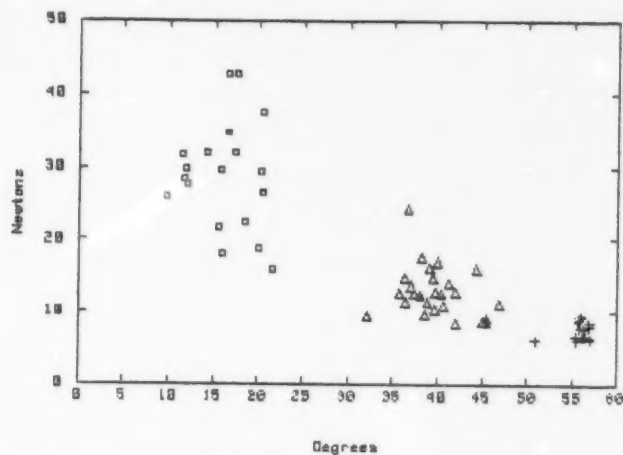
c)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0.30\text{m/s}$

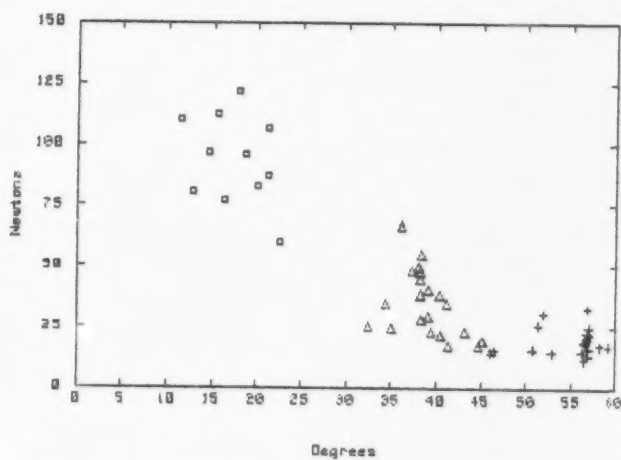
Figure 8.7 WATERPLANE ANGLES AT NORMAL FORCE MAXIMA FOR TESTS a) CW5, b) CW9, c) S32.

a)



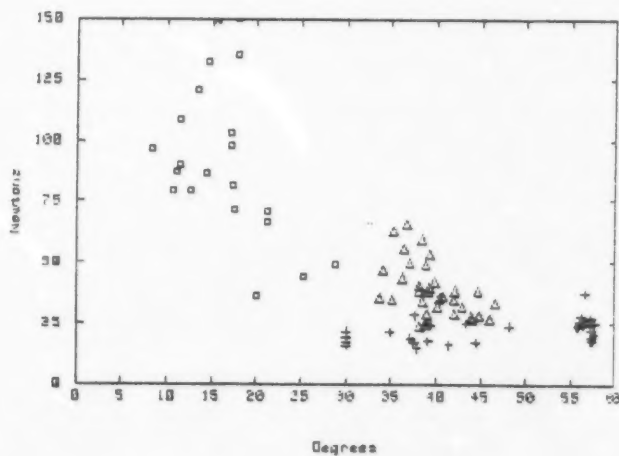
$h = 27\text{mm}$
 $\sigma_f = 25\text{kPa}$
 $V = 0.14\text{m/s}$

b)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0.22\text{m/s}$

c)



$h = 48\text{mm}$
 $\sigma_f = 30\text{kPa}$
 $V = 0.30\text{m/s}$

Figure 8.8 HULL FLARE ANGLES AT NORMAL FORCE MAXIMA FOR TESTS a) CW5, b) CW9, c) S32.

The friction coefficient at the instant a maximum force occurs is fairly constant on segments 2 and 3 at .08 to .15. This is significantly lower than the .10 to .25 which is the average friction coefficient over the entire time history. The friction force on segment 1 as shown in Figure 8.9 is very erratic ranging from 0.02 to 0.6 without any dependence on normal force. The low forces measured on segment 1 in combination with the observation that most of the ice loads are acting at or near the stem of the model where waterplane and flare angles change rapidly and cannot be accurately predicted probably accounts for a large error in prediction of the friction force.

Examining Figure 8.9 it does not seem that the friction force is strongly dependent on normal force at the time history peaks. It even appears that on segment 3 where most of the friction is theorized to occur that the friction coefficient is actually lower than it is on the further forward segment 2.

However, if the normal force is plotted versus friction force for the entire data set the friction coefficient is observed to exponentially decrease with increasing force. At a normal force in the range of 20 to 60 N the friction coefficient is larger on segment 3 than on segment 2 as shown in Figure 8.10.

The 30 second period of the time histories selected for analysis was examined to determine the frequency at which the peaks occur. If the peaks represent the moment at which a cusp breaks then the time interval between the peaks multiplied by the speed of the model should yield the distance between successive peaks. If each peak represents a separate cusp then the distance between peaks is the cusp length. Table 8.4 lists the average distance, for each segment of the three tests. A peak was counted every time the normal force rose above the average normal force of that segment and test and then fell below the average again. Also the characteristic length of the ice sheet is given.

While the characteristic length is three times larger on the 48 mm ice than on the 27 mm ice the distance between peak maxima on segments 1 and 2 only increases slightly and only doubles on segment 3.

The maxima occurrence on segments is consistent on segments 1 and 2 at 0.21 - 0.26 m in the 48 mm thick ice and 0.17 - 0.20 in the 27 mm ice. On segment 3 the distance between maxima more than doubles in the 48 mm ice to 0.60 m. In the thinner ice the increase is only about 1.5 to 1.75 times the distance on segments 1 and 2.

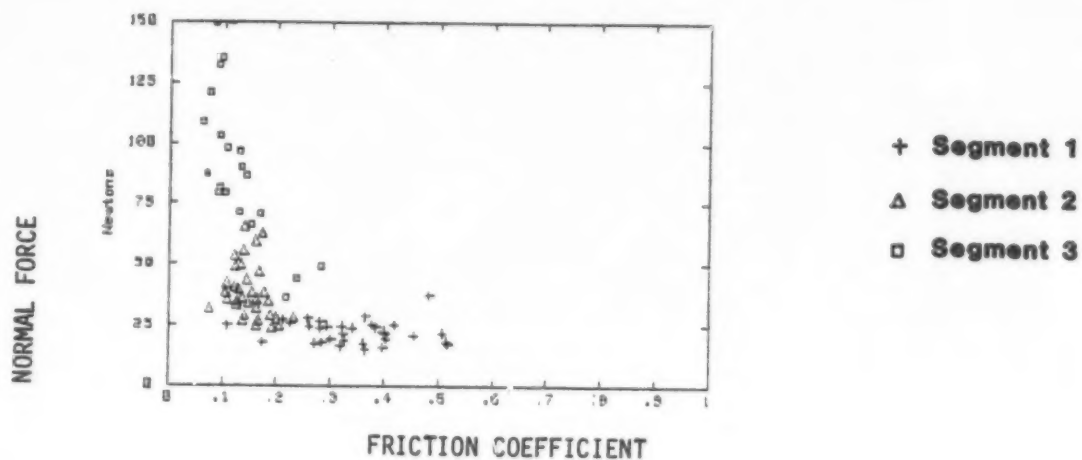


Figure 8.9 FRICTION COEFFICIENTS AT NORMAL FORCE MAXIMA DURING TEST S32 ($h = 48\text{mm}$, $\sigma_f = 30\text{kPa}$, $V = 0.30\text{m/s}$)

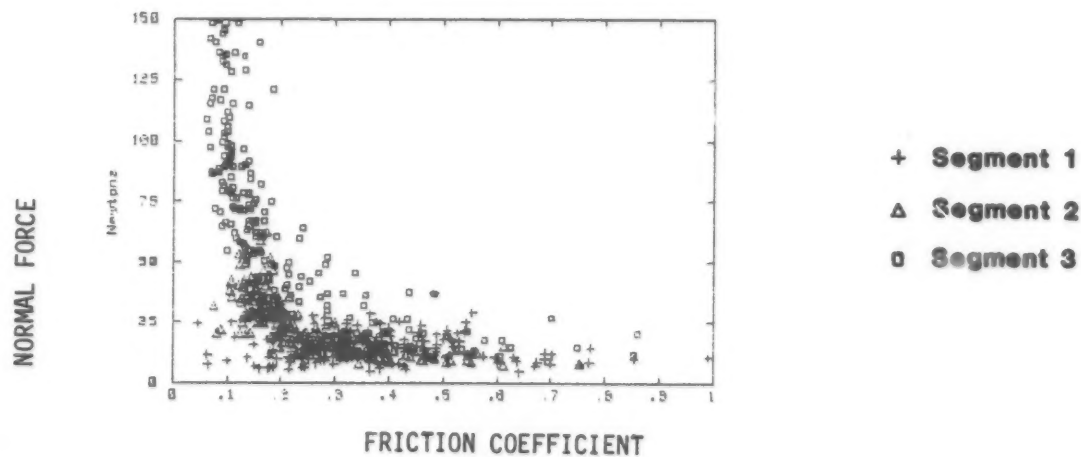


Figure 8.10 FRICTION COEFFICIENTS AT ALL NORMAL FORCE MEASUREMENTS DURING TEST S32 ($h = 48\text{mm}$, $\sigma_f = 30\text{kPa}$, $V = 0.30\text{m/s}$)

TABLE 8.4

DISTANCE BETWEEN ICE LOAD MAXIMA

TEST	CW5 avg.	CW9 avg.	S32 avg.
ice thickness mm	27	48	48
flexural strength KPa	25	30	30
characteristic length m	.12	.36	.36
Segment 1 (m)	.20	.21	.23
Segment 2 (m)	.17	.26	.25
Segment 3 (m)	.30	.60	.60

8.3 Video Correlation to Time History

During the ice sheet #3 test series a video camera was attached to the towing carriage so that the action of the ice on the segments could be filmed. A clock was connected to the video and set to correspond (with $\pm .10$ sec.) with the data acquisition system clock. This allowed for analysis of the video to determine if events recorded in the time history could be observed in the replay of the ice test. The video for test CW9 has been examined in this manner. Each segment was analyzed in turn. The results indicate a definite correlation between actual events and segment measurements. Several observations were made. Normal force maxima on segment 1 occur when the model has flexed the ice down about the bow at the instant or just after the cusp has been fully broken.

Time history maxima on segment 2 occur when the ice breaks and begins to turn. These peaks are very sharp occurring over .5 to .9 seconds. Cusp sliding and slapping up against the hull seem to be low force events.

On segment 3 the events were much harder to resolve. The ice pieces were usually turned on their side and travelling underwater especially on the last half of the segment. Some bending and cusp breaking occurred on the front third of the second. The time history maxima correspond to turning of ice pieces on the segment. As the ice turns it sometimes visibly slaps against the segment which also causes slightly smaller maxima. Ice bending did not seem to cause significant forces on the segment. Because of the low angle of the video camera it was not possible to observe if any ice crushing was taking place so no correlation of ice crushing to the normal force time history could be made.

9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Based on the results of the present experimental program the following conclusions may be made:

1. The problems of the segment support system have been resolved by using a stiffer preloading system. As a result the segments can now be accurately preloaded so that segment lift off does not occur during the ice testing. The stiffer preloading system has also decreased the segment movement during testing thereby reducing the zero offsets. The bearing surfaces on which the transducers act have been machined so that the error in load measurement is less than 1%.
2. The calibration rig which was built specifically to calibrate the segments lacks structural rigidity with the result being that the calibration rig is a potential source of error. Within these limitations segment correction factors and error bounds have been determined from the calibration results. Segment linearity and hysteresis is less than the overall segment error and in fact the hysteresis and nonlinearity detected was most likely a component of the random error associated with each segment. Repeat calibrations at the same point on each segment have confirmed the repeatability of the segment measurements.
3. Through segmentation the model has been developed into a working system which can measure ice loads, the frictional component of the load and its position and orientation on the segmented portion of the hull. A thorough model calibration has determined that for a 68% confidence limit the error bounds of the normal force are less than or equal to $\pm 13\%$ of the measurement depending on the segment and the error bounds of the friction force are $\pm 40\%$, $\pm 47\%$ and $\pm 14\%$ on segments 1, 2 and 3 respectively. While the error bounds of the friction force seem high the absolute value of the error is low due to the low magnitude of the friction force. The position of the force can be determined to $\pm 5\%$ of the segment length in the x direction and to within $\pm 7\%$ in the z direction. The friction direction can be determined within the error bounds of $\pm 15^\circ$ for friction coefficients greater than 0.2.
4. From the data collected during ice tests it was found that on all three segments the ice resistance was highly dependent on ice thickness and on the model speed. The breaking pattern, determined by the frequency of the ice load maxima, was roughly proportional to the ice thickness. The magnitude of the maximum forces decreased with increasing waterplane angle and increasing flare angle. As well a clear trend of exponentially increasing normal force with distance aft from

the bow was observed. The friction coefficient exponentially increased as the normal force decreased. The direction of the friction was very erratic but acted principally downward on segments 1 and 2 and slightly aft but still downwards on segment 3.

5. The ice tests were carried out using a fixed model so it was not necessary to correct the segment measurements for pitch, heave and roll. However, in separate static tests the sensitivity of the model to heave, pitch and roll was recorded and correcting factors for the motions were determined. The model is sensitive to roll and pitch and the correction factors would be required if the model was towed freely.

9.2 Recommendations

Several recommendations may be made to improve the level of technology developed to date. However, with a working model of the CCGS PIERRE RADISSON further applications of the model may be made in order to advance the state of our understanding of the icebreaking mechanisms and theory. Such applications will demonstrate the usefulness of the segmented model testing technique as a design tool for icebreaking ships. A more advanced stage of implementation addresses the next generation of modular segmented models. Specific recommendations in these three areas are stated below:

1. **Improvement of Technology:**

To improve the accuracy of the hull interpolation program the model lines should be lifted from segment 1 and added to the offsets already present in the routine. It is suggested that the data reduction algorithm be examined for improved and faster convergence on the solution. A new calibration rig using the design of the existing calibration rig but with stiffer components would eliminate the errors introduced by the calibration rig during the segment calibrations.

2. **Further Application of the Segmented RADISSON Model:**

a) The data collected shows a trend of increasing force with increasing distance from the bow and it is not possible to determine if the magnitude of the force decreases after the shoulder of the model (which occurs on segment 3) has been passed. The modification of the model to include a fourth segment immediately preceding segment 3 would allow measurement of forces on the parallel midbody and a more accurate description of the distribution of ice forces on the model.

b) A full complement of level ice tests should be performed to validate existing ice resistance theories such as Carter's, and Arctec Canada Limited's computer model "Resistance of Ice" (RICE). The ice thickness, ice flexural strength, model speed and friction coefficient should all be included as parameters in the test matrix. Specific aspects to examine would be the variation of normal force along the hull. The usual assumptions that ice moves along the buttocks or waterplanes can be compared to the measured friction direction.

c) The effect of friction factor on the hull should be studied in detail. Results from tests conducted indicated an exponential increase of friction factor with decreasing normal force. It is of relevance to establish whether this is a phenomenon or an artifact of the test. To determine this the friction factor can be varied by conventional means from 0.03 to 0.5 on the segments and ice test performed. The measurements can determine the dependent variables of the friction force and resolve any discrepancies in the measurement of the direction of friction.

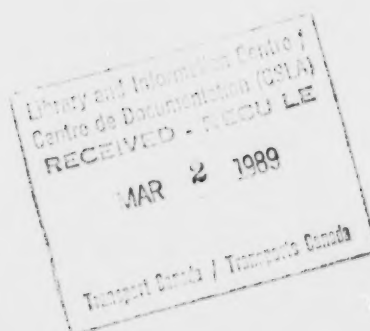
3. Future Generation of Segmented Models:

a) In order to facilitate the use of segmented models in the design and optimization of hull forms, it is desirable and cost effective to have a modular type base model with detachable segments. The latter can be removed and replaced with other hull form variation without need to change the segment support system or instrumentation. Therefore, the first step would be to design a core hull with a special versatile instrumentation system which permits liberal changes of the hull form in a wide range but with a basic segmentation plan.

b) The advanced version of segmented model should then be implemented to study a hull form of interest such as the POLAR 8 icebreaker. This will permit the detailed evaluation of candidate hull forms in order to substantiate the merits of these forms and provide an insight for possible means of improvement of performance.

REFERENCES

- [1] Nawwar, A.M., and Howard, D., "Segmented Model Testing in Ice - Development of Techniques", Transport Canada Report No. TP5701E, June 1984.
- [2] Edwards, R.Y. Jr., Nawwar, A.M., Noble, P.G., Dunne, M., "Development of a Research Program for Improving Arctic Marine Transportation Technology", submitted to Transport Canada Research and Development Center, 1979, Arctec Canada Report No. FR188C.
- [3] Nawwar, A.M., and Godon, A., "Arctic Ship Technology Hull Performance Prediction Techniques", submitted to Melville Shipping Ltd., October 1986, Arctec Canada Limited Report FR1915A.
- [4] Enkvist, E., "On the Ice Resistance Encountered by Ships Operating in the Continuous Mode of Icebreaking", the Swedish Academy of Engineering Science in Finland, Report No. 24, Helsinki, 1972.



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ICEBREAKING THEORY DEVELOPMENT
BY SEGMENTED MODEL TESTS:
REFINEMENT OF TECHNIQUE

VOLUME II

by

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MARCH 1987

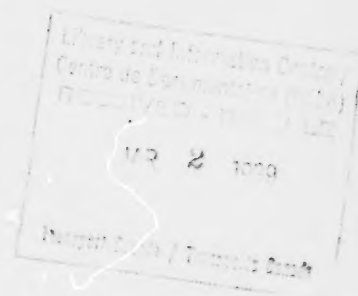
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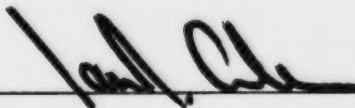
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NOMENCLATURE

C_1, C_2, C_3	moments about the x, y and z axis, respectively
d	vertical distance from 24.75' WL to r_2
$\vec{e}$	friction vector
E	modulus of elasticity
F	force
F_a	applied force
F_f	friction force
F_m	measured force
F_n	normal force
F_R, F_H, F_V	force in the longitudinal, horizontal and vertical direction respectively
F_{TOT}	total force
F_x, F_y, F_z	force in the x, y and z directions respectively (equivalent to F_R, F_H, F_V)
F_θ	force in the x-y plane which is normal to the waterline
H_{ij}	horizontal transducer j on segment i
$\vec{i}, \vec{j}, \vec{k}$	unit vectors on axes x, y z
k	spring stiffness
l_c	characteristic length
$\vec{n}$	vector normal to the hull surface
o'	origin of orthogonal coordinates at a point on the hull
NOR, T'_1, T'_V	calibration rig transducers
r_1	length of calibration rig arm which is along the model centerline
r_2	length of calibration rig arm which is normal to the waterline and parallel to the the waterplane
r_2'	distance from the centerline to r_3' at the 24.75' WL

r_3	length of calibration rig arm which is in the plane tangent to calibration point
r_3'	distance from 24.75' WL to calibration point in the plane tangent to the calibration point
R_{ij}	longitudinal transducer j on segment i
v	speed
V_{ij}	vertical transducer j on segment i
WL	waterline
x, y, z	left hand cartesian coordinates with origin at 24.75' WL, centerline and midships. x is the longitudinal direction, y is the horizontal direction and z is the downward vertical direction.
α	alpha - water line angle
α_c	angle between r_1 and r_2 minus 90°
β	beta - flare angle - angle from vertical of the buttock line
β_c	angle of calibration rig arm r_3 from the vertical
γ	correction factor
$\bar{\gamma}$	mean correction factor
ϵ_{RIG}	error of the calibration rig
ϵ_{SEG}	error of the segment
ϵ_{TOT}	total error of the calibration rig and segment
θ	Theta - normal flare angle; angle from the x-y plane of plane tangent to hull
μ	ratio of friction force to normal force
σ_f	flexural strength
σ_γ	standard deviation of the correction factor
ψ	Psi - angle from the x axis of $\vec{e}$
CL	hull centerline
	hull midships

APPENDIX A
DATA ACQUISITION AND REDUCTION SOFTWARE

A.1 DATA ACQUISITION PROGRAM

A listing of the Data Acquisition Program is given in this Appendix. The program performs the following functions:

- collects data
- stores data
- plots entire time history of each signal or a selected interval
- performs basic statistics on entire time history of each signal or a selected interval
- subtracts a zero value from the signals
- performs the data reduction algorithm on each segment to determine the normal and friction force and its location and orientation
- plots the normal force, friction force, x , z and μ and ψ values computed by the data reduction algorithm against time.

```

2  ! PROGRAM: 'ACLDAT' REVISED VERSION FOR BASIC 3.0
4  !
6  ! PROGRAMMERS: M. STEELE, ARTHUR KARTON & A GODON
8  ! VERSION:      3.0
10 ! DATE:         JAN 1987
12 !
14 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
16 !
18 PRINTER IS 1
20  GOSUB Init
22  GOSUB Read_calib
25  GOSUB Get_control_fil
26  GOSUB Input_testnum
28  GOSUB Softkeys
30  GOSUB Save_files
32  GOTO Finished
34  !
36 Init: !
38  OPTION BASE 1
40  COM /A110/ Job$(4),Nm$(4),Tst$(2),Run$(2)
42  COM /A111/ D0$(18),D1$(18),W0$(18),W1$(18),D2$(18)
44  COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Postrun
46  COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
48  COM /A114/ REAL Filt,Ttot,Digdate,Ztime
50  COM /A115/ REAL Conv(32),Unit$(32)(12),Cid$(32)(5)
52  !
54  COM /Gph0/ Title$(80),Plotlist$(20,5)(5),Pglabel$(20,5)(20)
56  COM /Gph1/ Pgstat$(20,5)(3),Pgsignal$(20,5)(20)
58  COM /Gph2/ INTEGER Zerolow,Zerohigh,Power2low,Power2high
60  COM /Gph3/ INTEGER Pages,Datalow(6),Datahigh(6)
62  COM /Gph4/ REAL Xzer(32),Scalemin(20,5),Scalemax(20,5)
64  !
66  COM /Calib/ REAL Slope(32),Intercept(32)
68  GRAPHICS OFF
70  PRINT USING "0"
72  W0$=":",700"           ! HARD DISK
74  D0$=":",704,0"         ! LEFT HAND FLOPPY
76  D1$=":",704,1"         ! RIGHT HAND FLOPPY
78  D2$=":",702"           ! FLOPPY IN 9133XXV
80 ! MASS STORAGE IS W0$
82 ! LOAD KEY "CLEAR"
83  GOSUB Setdatetime
85  Stop_chan=32
86  Firstscan=1
88  Postrun=0
90  Gpio=12
92  Pr=701
94  Crt=1
96  RETURN
98  !
100 !

```

```

101 !.....
102 !
103 Setdatetime: !
104 GOSUB Clearkeys
105 ON ERROR GOTO Time_loop
106 PRINT CHR$(12)
107 ON KEY 5 LABEL " TIME OK",12 GOTO Set_date_return
108 ON KEY 6 LABEL " CHANGE",12 GOTO Change_timedate
109 Time_loop: !
110 Ti=TIMEDATE
111 DISP DATE$(Ti);" ";TIME$(Ti)
112 GOTO Time_loop
113 Change_timedate: !
114 Z$=DATE$(TIMEDATE)
115 ZI$=TIME$(TIMEDATE)
116 INPUT "Enter date in form 'DD MMM YYYY', eg. 19 AUG 1985",Z$
117 SET TIMEDATE DATE(Z$)
118 Hours=999
119 INPUT "Enter hours",Hours
120 IF Hours=999 THEN Hours=VAL(ZI$[1,2])
121 Minutes=999
122 INPUT "Enter minutes",Minutes
123 IF Minutes=999 THEN Minutes=VAL(ZI$[4,5])
124 Seconds=999
125 INPUT "Enter seconds",Seconds
126 IF Seconds=999 THEN Seconds=VAL(ZI$[7,8])
127 SET TIME (Hours*3600)+(Minutes*60)+Seconds
128 GOTO Time_loop
129 Set_date_return: !
130 OFF ERROR
131 PRINT CHR$(12)
132 DISP ""
133 RETURN
134 !
135 !.....
136 !
137 Read_calib: !
138 ! SLOPE 1 - 32
139 DATA 1.0021,1.0021,1.0021,1.0021,1.0021,1.0027,1.0027,1.0027,1.0021
140 DATA 1.0024,1.0021,1.00205,1.00205,1.0021,1.0027,1.0021,1.0087
141 DATA 1.0090,1.0087,1.0083,1.0090,1.0090,1.0090,1.0055,1.0087,1.0090
142 DATA 1.0083,1.0083,1.0083,1.0083,1.0083,1.0090
143 RESTORE 139
144 FOR I=1 TO 32
145 READ Slope(I)
146 NEXT I
147 ! INTERCEPT 1-32
148 DATA 10.1566,19.1751,10.1566,7.9859,19.1751,27.4783,34.4975,24.47
149 DATA 9.1546,19.3157,10.1566,8.15254,20.1772,28.1936,31.4892
150 DATA 22.1813,23.5401,24.6921,25.5574,28.4389,21.665,25.7011
151 DATA 26.7101,29.9692,23.5401,27.7192,23.3972,27.095,23.2294
152 DATA 25.4139,26.4222,27.7192

```



```

153 RESTORE 148
154 FOR I=1 TO 32
155   READ Intercept(I)
156 NEXT I
157 RETURN
158 !
159 Get_control_fil:|
160 Readflag=0
161 CALL Confile(Readflag)
162 RETURN
163 !
164 Input_testnum:|
165 INPUT "INPUT TEST CODE ( 2 characters)",Tst$
166 IF LEN(Tst$)<>2 THEN GOTO Input_testnum
167 Inrun:|
168 INPUT "INPUT RUN #",Run
169 Run$=VAL$(Run)
170 IF LEN(Run$)>2 THEN GOTO Inrun
171 Nm$=Tst$&Run$
172 PRINT USING "@"
173 Firstscan=1
174 Storeflag=0
175 INPUT "DO YOU WANT TO EDIT THE PARAMETER FILE",Parmans$
176 IF Parmans$="Y" THEN
182   DISP "CREATING RUN PARAMETER FILE: ",Nm$
184   INPUT "ENTER NPTS",Npts
185   INPUT "ENTER CONV(11)",Conv(11)
187   Storeflag=1
188 END IF
189 CALL Runread(Storeflag)
190 RETURN
191 !
192 Softkeys:|
193 PRINT USING "@"
194 DISP ""
195 ON KEY 0 LABEL " SCAN CONTROL" GOTO Scancon
196 ON KEY 1 LABEL " GRAPH CONTROL" GOTO Graphcon
197 ON KEY 2 LABEL "" GOTO Softkeys
198 ON KEY 3 LABEL " TEST/RUN#" GOTO Input_testrun
199 ON KEY 4 LABEL " EXIT " GOTO Exit_keys
200 ON KEY 5 LABEL " SCAN" GOTO Scan
201 ON KEY 6 LABEL " GRAPH" GOTO Graph
202 ON KEY 7 LABEL " SEPARATE" GOTO Separate
203 ON KEY 8 LABEL "" GOTO Softkeys
204 ON KEY 9 LABEL " SET TIME " GOTO Set_time
205 Wait_for_key:|
206 GOTO Wait_for_key
207 !
208 Save_files:|
209 Storeflag=1
210 CALL Confile(Storeflag)
211 Storeflag=1

```

```

212 CALL Runread(Storeflag)
213 Postrun=1
214 DISP ""
215 RETURN
216 !
217 Scancon: !
218 GOSUB Clearkeys
219 CALL Scan_control
220 GOTO Softkeys
221 Scan: !
222 GOSUB Clearkeys
223 IF NOT Firstscan THEN
224     Run=Run+1
225     Nm$=Tst$&VAL$(Run)
226 END IF
227 CALL Scan
228 GOTO Softkeys
229 Graphcon: !
230 GOSUB Clearkeys
231 CALL Graph_control
232 GOTO Softkeys
233 Graph: !
234 GOSUB Clearkeys
235 CALL Graph
236 GOTO Softkeys
237 Input_testrun: !
238 GOSUB Input_testnum
239 GOTO Softkeys
240 Separate: !
241 GOSUB Clearkeys
242 CALL Separate
243 GOTO Softkeys
244 Set_time: !
245 GOSUB Clearkeys
246 CALL Set_time
247 GOTO Softkeys
248 Exit_keys: !
249 GOSUB Clearkeys
250 RETURN
251 !
252 Clearkeys: !
253 FOR Keynum=0 TO 9
254     ON KEY Keynum LABEL "" GOSUB Dummy
255 NEXT Keynum
256 RETURN
257 !
258 Dummy: !
259 RETURN
260 !
261 Finished: !
262 END
263 !

```

```

264 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
265 !
266 SUB Scan
267 !          LENGTH OF SCAN IS DETERMINED BY THE SIZE OF
268 !          BUFF1 AS SET IN THE 'ASSIGN' STATEMENT
269 !          BUFFER SIZE= NCHANS*NSECS*HZ*2
270 GOSUB Init
271 GOSUB Assign_buffers
272 GOSUB Collect_zeros
273 GOSUB Digitize
274 GOSUB Store_buffer
275 GOSUB Store_runfile
276 GOTO Sub_end
277 !
278 Init: !
279 OPTION BASE 1
280 COM /A110/ Job$,Nm$,Tst$,Run$
281 COM /A111/ D0$,D1$,W0$,W1$,D2$
282 COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Posrun
283 COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
284 COM /A114/ REAL Filt,Ttot,Digdate,Ztime
285 COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
286 !
287 PRINT USING "@"
288 INTEGER I,J,Chan,Rec,Address,Zerocount,St_chan
289 Firstscan=0
290 Zerocount=Hz ! Zerocount determines size of buffer
291 IF Hz=0 THEN Zerocount=256 ! for collecting zeros on all chans -
292 IF Zerocount>511 THEN Zerocount=511 ! must be less than 512 to avoid
293 ! Integer Overflow
294 PRINT "Z= ";Zerocount
295 !
296 IF Start_chan=16 THEN Start_chan=15 !!!! HARDWARE LIMITATION
297 Nchan=Stop_chan-Start_chan+1
298 St_chan=Start_chan-1 !!!!! OPTION BASE 0 FOR ACQ UNIT
299 IF St_chan>15 THEN
300 Address=(St_chan-16)*256+2^4
301 ELSE
302 Address=BINAND(15,St_chan)
303 END IF
304 RETURN
305 !
306 !
307 Assign_buffers: !
308 PRINT CHR$(12)
309 ASSIGN @Gpio TO Gpio;FORMAT OFF,WORD
310 ASSIGN @Buff1 TO BUFFER [400000];FORMAT OFF,WORD ! NCHANS*NSECS*HZ*2
311 ASSIGN @Buff2 TO BUFFER [Nchan*Zerocount*2];FORMAT OFF,WORD
312 RETURN
313 !
314 Collect_zeros: !
315 INPUT "PRESS CONT FOR ZERO COLLECTION",Zz$

```

```

316 OUTPUT @Gpio USING "#,W";Address ! OUTPUT FIRST CHAN#
317 CONTROL 12,0;1 ! reset Gpio <write anything to register #0
318 RESET @Buff2
319 TRANSFER @Gpio TO @Buff2;COUNT 2,WAIT
320 RESET @Buff2
321 T1=TIMEDATE
322 TRANSFER @Gpio TO @Buff2;WAIT
323 T1=TIMEDATE-T1
324 RETURN
325 !
326 Digitize: !
327             ! N.B. TRANSFER RATES
328             !
329             ! Adding the WAIT parameter to the
330             ! TRANSFER @GPIO TO @BUFF1 statement will
331             ! increase the sampling rate from approx.
332             ! 190 Hz/chan to 248 Hz/chan for 32 channels
333             ! However, the ABORT and END OF TEST softkeys
334             ! will not be able to interrupt the sampling
335             !
336 ON KEY 5 LABEL " END OF TEST" GOTO End_of_transfer
337 ON KEY 0 LABEL " ABORT" GOTO Abort_transfer
338 INPUT "PRESS <CONT> TO BEGIN TRANSFER",Zz$
339 BEEP
340 OUTPUT @Gpio USING "#,W";Address ! OUTPUT FIRST CHAN#
341 CONTROL 12,0;1 ! reset Gpio <write anything to register #0
342 RESET @Buff1
343 TRANSFER @Gpio TO @Buff1;COUNT 2,WAIT
344 RESET @Buff1
345 T2=TIMEDATE ! Set stopwatch
346 TRANSFER @Gpio TO @Buff1;WAIT
347 BEEP
348 DISP "RECEIVING DATA"
349 !DISP "RECEIVING DATA: PRESS KEY 5 TO END TRANSFER OR KEY 0 TO ABORT"
350 !STATUS @Buff1,10;Tstat
351 !IF Tstat>=64 THEN GOTO 673
352 GOTO End_of_transfer
353 !
354 Abort_transfer: !
355 ABORTIO @Gpio
356 Time=TIMEDATE-T2+T1
357 Digate=T2
358 PRINT CHR$(12)
359 INPUT "STORE DATA? <Y> <N>",Zz$
360 IF Zz$="Y" THEN GOTO 368
361 GOTO 338
362 !
363 End_of_transfer: !
364 ABORTIO @Gpio
365 Time=TIMEDATE-T2+T1
366 Digdate=T2
367 DISP "TRANSFER COMPLETE"

```

```

368 ASSIGN @Gpio TO *
369 STATUS @Buff1,4;Inbytes
370 Total_points=Inbytes/2
371 Npts=Total_points/Nchan+Zerocount
372 Num_recs=Inbytes/16384+3
373 Hz=INT(Npts/Time)
374 !PRINT "RATE per CH ";Hz;" DURATION OF SCAN ";Time
375 !PRINT "INBY= ";Inbytes;" NPTS= ";Npts;" TOTAL= ";Total_points
376 RETURN
377 !
378 Store_buffer: !
379 DISP "STORING RUN DATA IN FILE: ",Nm$&"ALL"
380 CREATE BDAT Nm$&"ALL"&W0$,Num_recs,16384
381 ASSIGN @Store TO Nm$&"ALL"&W0$
382 TRANSFER @Buff2 TO @Store;WAIT
383 TRANSFER @Buff1 TO @Store;WAIT
384 ASSIGN @Store TO *
385 ASSIGN @Buff1 TO *
386 ASSIGN @Buff2 TO *
387 RETURN
388 !
389 Store_runfile: !
390 DISP "CREATING RUN PARAMETER FILE: ",Nm$
391 CREATE BDAT Nm$&D0$,Nchan+1,80
392 Storeflag=1
393 CALL Runread(Storeflag)
394 Postrun=1
395 RETURN
396 !
397 Sub_end: !
398 SUBEND
399 !
400 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
401 !
402 SUB Scan_control
403 GOSUB Init
404 GOSUB Init_header1
405 GOSUB Display_page1
406 GOSUB Key_selections
407 GOSUB Init_page2
408 GOSUB Display_page2
409 GOSUB Editkeys
410 IF Changed1 OR Changed2 THEN GOSUB Rewrite
411 GOTO Sub_exit
412 !
413 Init: !
414 OPTION BASE 1
415 COM /A110/ Job$,Nm$,Tst$,Run$
416 COM /A111/ D0$,D1$,W0$,W1$,D2$
417 COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Postrun
418 COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
419 COM /A114/ REAL Filt,Ttot,Digdate,Ztime

```

```

420 COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
421 !
422 INTEGER Chan,First_chan,Last_chan,Chans_per_page,Linenum,Firstline
423 Image1: IMAGE 30A,5D,D,2X,2A
424 Image2: IMAGE 30A,7D
425 !
426 PRINTER IS CRT
427 Changed1=0
428 Changed2=0
429 ON KEY 8 LABEL " PRINTER ON" GOSUB Printer_on
430 ON KEY 9 LABEL " PRINTER OFF" GOSUB Printer_off
431 RETURN
432 !
433 Init_header1: !
434 PRINT
435 PRINT TAB(33);"Scan Control"
436 PRINT
437 PRINT TAB(25);"*** DIGITIZING PARAMETERS ***"
438 PRINT
439 PRINT TAB(31);"TEST ";Nm$(1;21);" RUN ";Nm$(3;21)
440 PRINT
441 RETURN
442 !
443 Display_page1: !
444 IF Hz<>0 THEN Skip1
445 Hz=5
446 Filt=0
447 Start_chan=16
448 Stop_chan=32
449 Nchan=Stop_chan-Start_chan+1
450 Skip1: !
451 PRINT TABXY(1,9)
452 PRINT USING Image2;"START CHANNEL:";Start_chan
453 PRINT USING Image2;"END CHANNEL:";Stop_chan
454 PRINT USING Image2;"TOTAL # OF CHANNELS:";Nchan
455 PRINT USING Image1;"DIGITIZING FREQUENCY/CHANNEL:";Hz,"Hz"
456 PRINT USING Image1;"SYSTEM DIGITIZING FREQUENCY:";Hz*Nchan,"Hz"
457 PRINT USING Image1;"FILTER FREQUENCY:";Filt,"HZ"
458 DISP "Note: START CHANNEL IS the only software parameter."
459 IF Changed1 AND Postrun THEN
460 PRINT
461 PRINT CHR$(129),"INFO CHANGED AFTER DIGITIZING",CHR$(128)
462 END IF
463 RETURN
464 !
465 Key_selections: !
466 ON KEY 5 LABEL " ALL OK" GOTO End_page1
467 ON KEY 6 LABEL " CHANGES" GOSUB Change_page1
468 GOTO Key_selections
469 End_page1: !
470 DISP ""
471 OFF KEY 5

```



```

472 OFF KEY 6
473 RETURN
474 !
475 Change_page1: !
476 INPUT "ENTER NEW START CHANNEL OR <CONT> ", Start_chan
477 Nchan=Stop_chan-Start_chan+1
478 Changed1=!
479 GOSUB Display_page1
480 RETURN
481 !
482 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
483 !
484 Init_page2: !
485 Startflg=1
486 Chan=Start_chan
487 Chans_per_page=11
488 Linenum=1
489 First_chan=Start_chan
490 Last_chan=Start_chan+Chans_per_page-1
491 IF Last_chan>Stop_chan THEN Last_chan=Stop_chan
492 Firstline=5
493 Head1: IMAGE 5X,15A,16A,18A,18A
494 Line1: IMAGE 8X,0D,13X,10A,3X,MD,DDDE,10X,Z0A
495 RETURN
496 !
497 Display_page2: !
498 PRINT USING "0"
499 GOSUB Header
500 GOSUB Display_chans
501 IF Startflg THEN
502     Chan=First_chan
503     Linenum=Firstline+1
504     Startflg=0
505 END IF
506 PRINT CHR$(129)
507 PRINT TABXY(1,Linenum)
508 PRINT USING Line1:Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
509 PRINT CHR$(128)
510 RETURN
511 !
512 Editkeys: !
513 ON KEY 0 LABEL " NEXT PAGE" GOSUB Next_page
514 ON KEY 1 LABEL "" GOSUB Dummy
515 ON KEY 2 LABEL " PRINT TABLE" GOSUB Printtable
516 ON KEY 3 LABEL "" GOSUB Dummy
517 ON KEY 4 LABEL " EXIT" GOTO End_page2
518 ON KEY 5 LABEL " MODIFY" GOSUB Modify_channel
519 ON KEY 6 LABEL " DELETE " GOSUB Delete_channel
520 ON KEY 7 LABEL " INSERT " GOSUB Insert_channel
521 ON KEY 8 LABEL "" GOSUB Dummy
522 ON KEY 9 LABEL " NEXT CHANNEL" GOSUB Next_channel
523 Wait_for_select: !

```

```

524 GOTO Editkeys
525 !
526 Dummy: !
527 RETURN
528 !
529 End_page2: !
530 RETURN
531 !
532 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
533 !
534 Delete_channel: !
535 No_channels=0
536 IF Nchan=0 THEN No_channels=1
537 IF No_channels THEN
538     DISP "NO CHANNELS TO DELETE"
539     WAIT 1.5
540     GOTO Del_return
541 END IF
542 Changed2=1
543 IF Nchan=1 THEN
544     PRINT TABXY(1,Firstline+1)
545     PRINT USING "80A";""
546     Nchan=0
547     GOTO Del_return
548 END IF
549 FOR I=Chan TO Start_chan+1 STEP -1
550     Cid$(I)=Cid$(I-1)
551     Conv(I)=Conv(I-1)
552     Unit$(I)=Unit$(I-1)
553 NEXT I
554 Nchan=Nchan-1
555 Start_chan=Start_chan+1
556 IF Start_chan>First_chan THEN
557     First_chan=Start_chan
558     Chan=First_chan
559 END IF
560 Last_chan=First_chan+Chans_per_page-1
561 IF Last_chan>Stop_chan THEN Last_chan=Stop_chan
562 IF Chan<First_chan THEN Chan=First_chan
563 IF Chan<>First_chan AND Start_chan=First_chan THEN Linenum=Linenum-1
564 IF Chan=First_chan THEN Linenum=Firstline+1
565 PRINT TABXY(1,Firstline+1)
566 GOSUB Display_chans
567 IF Nchan=0 THEN Del_return
568 PRINT CHR$(129)
569 PRINT TABXY(1,Linenum)
570 PRINT USING Linel;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
571 PRINT CHR$(128)
572 Del_return: !
573 RETURN
574 !
575 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

```

```

576 !
577 Insert_channel: !
578 IF Start_chan=1 THEN
579     DISP "32 CHANNELS ALREADY SELECTED"
580     WAIT 1.5
581     GOTO Ins_return
582 END IF
583 Changed2=1
584 Start_chan=Start_chan-1
585 Chan=Chan-1
586 FOR I=Start_chan TO Chan-1
587     Cid$(I)=Cid$(I+1)
588     Conv(I)=Conv(I+1)
589     Unit$(I)=Unit$(I+1)
590 NEXT I
591 GOSUB Channel_input
592 Nchan=Nchan+1
593 IF First_chan<>Start_chan THEN First_chan=First_chan-1
594 IF Last_chan-First_chan+1>Chans_per_page THEN Last_chan=Last_chan-1
595 PRINT TABXY(1,Firstline+1)
596 GOSUB Display_chans
597 Chan=First_chan
598 PRINT CHR$(129)
599 Linenum=Firstline+1
600 PRINT TABXY(1,Linenum)
601 PRINT USING Linel;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
602 PRINT CHR$(128)
603 Ins_return: !
604 RETURN
605 !
606 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
607 !
608 Modify_channel: !
609 No_channels=0
610 IF Nchan=0 THEN No_channels=1
611 IF No_channels THEN
612     DISP "NO CHANNELS TO MODIFY"
613     WAIT 1.5
614     GOTO Do_select
615 END IF
616 Changed2=1
617 GOSUB Channel_input
618 PRINT TABXY(1,Linenum);CHR$(129)
619 PRINT USING Linel;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
620 PRINT TABXY(1,1);CHR$(128)
621 RETURN
622 !
623 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
624 !
625 Channel_input: !
626 INPUT "CHANNEL ID?",Cid$(Chan)
627 INPUT "CONVERSION FACTOR?",Conv(Chan)

```

```

628 INPUT "ENGINEERING UNITS?",Unit$(Chan)
629 RETURN
630 !
631 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
632 !
633 Display_chans: !
634 Temp_chan=Chan
635 FOR Chan=First_chan TO Last_chan
636 PRINT USING Line1;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
637 NEXT Chan
638 Chanlines=Last_chan-First_chan+1
639 IF Chanlines MOD Chans_per_page<>0 THEN
640 PRINT USING "80A";" "
641 Chanlines=Chanlines+1
642 GOTO 639
643 END IF
644 Chan=Temp_chan
645 RETURN
646 !
647 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
648 !
649 Next_channel: !
650 PRINT TABXY(1,Linenum)
651 PRINT USING Line1;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
652 Chan=Chan+1
653 Linenum=Linenum+1
654 IF Linenum>Firstline+Chans_per_page OR Chan>Last_chan THEN
655 Chan=First_chan
656 Linenum=Firstline+1
657 END IF
658 PRINT CHR$(129)
659 PRINT TABXY(1,Linenum)
660 PRINT USING Line1;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
661 PRINT CHR$(128)
662 No_change: !
663 RETURN
664 !
665 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
666 !
667 Next_page: !
668 First_chan=First_chan+Chans_per_page
669 Last_chan=Last_chan+Chans_per_page
670 IF Last_chan>Stop_chan AND First_chan<=Stop_chan THEN Last_chan=Stop_chan
671 IF First_chan>Stop_chan THEN
672 First_chan=Start_chan
673 Last_chan=Start_chan+Chans_per_page-1
674 END IF
675 IF Last_chan>Stop_chan THEN Last_chan=Stop_chan
676 PRINT TABXY(1,Firstline+1)
677 GOSUB Display_chans
678 PRINT CHR$(129)
679 Linenum=Firstline+1

```

```

680 PRINT TABXY(1,Linenum)
681 Chan=First_chan
682 PRINT USING Linel;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
683 PRINT CHR$(128)
684 RETURN
685 !
686 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
687 !
688 Header: !
689 PRINT USING "0"
690 PRINT TAB(30);"CHANNEL ASSIGNMENTS"
691 PRINT TAB(31);"TEST ";Nm$(1;2);" RUN ";Nm$(3;2)
692 PRINT
693 PRINT USING Head1;"CHANNEL #","CHANNEL ID","CONV FACTOR","ENG. UNITS (/VOL
T)"
694 PRINT
695 RETURN
696 !
697 Rewrite: !
698 IF Changed2 AND Postrun THEN
699 PRINT TABXY(1,18)
700 PRINT CHR$(129)
701 PRINT "INFO CHANGED AFTER DIGITIZING"
702 PRINT CHR$(128)
703 Zz$=""
704 INPUT "PRESS <CONT> TO STORE NEW INFO, <N> TO KEEP OLD INFO",Zz$
705 END IF
706 IF Zz$="N" THEN Rewrite_exit
707 Storeflag=1
708 CALL Confile(Storeflag)
709 Postrun=1
710 Storeflag=1
711 CALL Runread(Storeflag)
712 Rewrite_exit: !
713 RETURN
714 !
715 Printtable: !
716 PRINTER IS PRT
717 GOSUB Header
718 FOR Chan=Start_chan TO Stop_chan
719 PRINT USING Linel;Chan,Cid$(Chan),Conv(Chan),Unit$(Chan)
720 NEXT Chan
721 PRINTER IS CRT
722 RETURN
723 !
724 Printer_on: !
725 PRINTER IS Pr
726 DISP "PRINTER IS ON"
727 WAIT 1
728 DISP ""
729 RETURN
730 !

```

```

731 Printer_off: !
732 PRINTER IS CRT
733 DISP "PRINTER IS OFF"
734 WAIT 1
735 DISP ""
736 RETURN
737 !
738 Sub_exit: !
739 DISP ""
740 SUBEND
741 !
742 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
743 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
744 SUB Graph_control
745 GOSUB Init
746 GOSUB Clearkeys
747 GOSUB Display_page
748 GOSUB Mainkeys
749 Storeflag=1
750 CALL Confile(Storeflag)
751 GOTO Sub_exit
752 !
753 Init: !
754 OPTION BASE 1
755 COM /A110/ Job$,Nm$,Tst$,Run$
756 COM /A111/ D0$,D1$,W0$,W1$,D2$
757 COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Posrun
758 COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
759 COM /A114/ REAL Filt,Ttot,Digdate,Ztime
760 COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
761 !
762 COM /Gph0/ Title$,Plotlist$(*),Pglabel$(*)
763 COM /Gph1/ Pgstat$(*),Pgsignal$(*)
764 COM /Gph2/ INTEGER Zerolow,Zerohigh,Power2low,Power2high
765 COM /Gph3/ INTEGER Pages,Datalow(*),Datahigh(*)
766 COM /Gph4/ REAL Xzer(*),Scalemin(*),Scalemax(*)
767 !
768 INTEGER Page,Firstline,Linenum,Maxplots,Lastnplot,Maxpages,Stats_flag
769 INTEGER Prntflag
770 Head1: IMAGE 9A,22A,25A,16A,8A
771 Head2: IMAGE 11X,22A,18A,12A,7A,10A
772 Line1: IMAGE 9A,22A,17A,SD.DE,4X,SD.DE,5X,4A
773 Pages=0
774 X=1
775 WHILE Plotlist$(X,1)<>""
776 Pages=X
777 X=X+1
778 END WHILE
779 Page=1
780 Linenum=1
781 Firstline=6
782 Maxplots=5

```



```

783 Maxpages=20
784 Prntflag=0
785 PRINTER IS CRT
786 PRINT USING "e"
787 RETURN
788 !
789 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
790 !
791 Mainkeys: !
792 ON KEY 0 LABEL " NEXT PAGE" GOSUB Next_page
793 ON KEY 1 LABEL " NEW PAGE" GOSUB New_page
794 ON KEY 2 LABEL " DELETE PAGE" GOSUB Delete_page
795 ON KEY 3 LABEL " PRINT TABLE" GOSUB Print_table
796 ON KEY 4 LABEL " EXIT" GOTO Exit_graphcon
797 ON KEY 5 LABEL " MODIFY" GOSUB Modify_channel
798 ON KEY 6 LABEL " DELETE CHAN" GOSUB Delete_channel
799 ON KEY 7 LABEL " ADD CHANNEL" GOSUB Add_channel
800 ON KEY 8 LABEL "" GOTO Mainkeys
801 ON KEY 9 LABEL " NEXT CHANNEL" GOSUB Next_channel
802 GOTO Mainkeys
803 !
804 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
805 !
806 New_page: !
807 X=1
808 WHILE Plotlist$(X,1)<>""
809 X=X+1
810 END WHILE
811 IF X>Maxpages THEN
812 DISP "ONLY ";Maxpages;" PAGES ALLOWED"
813 WAIT 1
814 DISP ""
815 GOTO Mainkeys
816 END IF
817 Pages=X
818 Page=Pages
819 GOSUB Display_page
820 RETURN
821 !
822 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
823 !
824 Next_page: !
825 Page=Page+1
826 GOSUB Display_page
827 RETURN
828 !
829 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
830 !
831 Display_page: !
832 IF Page>Pages THEN Page=1
833 GOSUB Header
834 GOSUB Display_chans

```

```

835 RETURN
836 !
837 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
838 !
839 Modify_channel: !
840 GOSUB Input_channel
841 Linenum=Firstline+Nplot
842 PRINT CHR$(129)
843 PRINT TABXY(1,Linenum)
844 I=Page
845 J=Nplot
846 PRINT USING Line1;Plotlist$(I,J),Pgsignal$(I,J),Pglabel$(I,J),Scalemin(I,J
),Scalemax(I,J),Pgstat$(I,J)
847 PRINT CHR$(128)
848 RETURN
849 !
850 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
851 !
852 Add_channel: !
853 IF Plotspage=Maxplots THEN
854     DISP "ONLY ";Maxplots;" PLOTS/PAGE ALLOWED"
855     WAIT 1
856     DISP ""
857     GOTO Add_exit
858 END IF
859 Lastnplot=Nplot
860 Plotspage=Plotspage+1
861 Linenum=Firstline+Plotspage
862 Nplot=Plotspage
863 GOSUB Input_channel
864 PRINT TABXY(1,Firstline+Lastnplot)
865 IF Nplot>1 THEN
866     I=Page
867     J=Lastnplot
868     PRINT USING Line1;Plotlist$(I,J),Pgsignal$(I,J),Pglabel$(I,J),Scalemin
(I,J),Scalemax(I,J),Pgstat$(I,J)
869 END IF
870 PRINT CHR$(129)
871 PRINT TABXY(1,Linenum)
872 I=Page
873 J=Nplot
874 PRINT USING Line1;Plotlist$(I,J),Pgsignal$(I,J),Pglabel$(I,J),Scalemin(I,J
),Scalemax(I,J),Pgstat$(I,J)
875 PRINT CHR$(128)
876 Add_exit: !
877 RETURN
878 !
879 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
880 !
881 Delete_channel: !
882 IF Plotspage=0 THEN
883     DISP "NO CHANNELS TO DELETE"

```

```

884     WAIT 1
885     DISP ""
886     GOTO Del_exit
887 END IF
888 FOR J=Nplot TO Maxplots-1
889     Plotlist$(Page,J)=Plotlist$(Page,J+1)
890     Pgsignal$(Page,J)=Pgsignal$(Page,J+1)
891     Pglabel$(Page,J)=Pglabel$(Page,J+1)
892     Scalemin(Page,J)=Scalemin(Page,J+1)
893     Scalemax(Page,J)=Scalemax(Page,J+1)
894     Pgstat$(Page,J)=Pgstat$(Page,J+1)
895 NEXT J
896 Plotspage=Plotspage-1
897 FOR J=Plotspage+1 TO Maxplots
898     Plotlist$(Page,J)=""
899 NEXT J
900 GOSUB Display_chans
901 IF Plotspage=0 THEN GOSUB Delete_page
902 Del_exit: 1
903 RETURN
904 !
905 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
906 !
907 Next_channel: 1
908 Linenum=Firstline+Nplot
909 PRINT TABXY(1,Linenum)
910 I=Page
911 J=Nplot
912 PRINT USING Line1;Plotlist$(I,J),Pgsignal$(I,J),Pglabel$(I,J),Scalemin(I,J
),Scalemax(I,J),Pgstat$(I,J)
913 IF Nplot+1>Plotspage THEN
914     Nplot=1
915     Linenum=Firstline+1
916 ELSE
917     Nplot=Nplot+1
918 END IF
919 PRINT CHR$(129)
920 Linenum=Firstline+Nplot
921 PRINT TABXY(1,Linenum)
922 I=Page
923 J=Nplot
924 PRINT USING Line1;Plotlist$(I,J),Pgsignal$(I,J),Pglabel$(I,J),Scalemin(I,J
),Scalemax(I,J),Pgstat$(I,J)
925 PRINT CHR$(128)
926 RETURN
927 !
928 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
929 !
930 Delete_page: 1
931 IF Page<>Pages THEN
932     FOR I=Page TO Pages-1
933         FOR J=1 TO Maxplots

```

```

934         Plotlist$(I,J)=Plotlist$(I+1,J)
935         Plotlist$(I+1,J)=""
936         Pgsignal$(I,J)=Pgsignal$(I+1,J)
937         Pglabel$(I,J)=Pglabel$(I+1,J)
938         Scalemin(I,J)=Scalemin(I+1,J)
939         Scalemax(I,J)=Scalemax(I+1,J)
940         Pgstat$(I,J)=Pgstat$(I+1,J)
941     NEXT J
942 NEXT I
943 END IF
944 Pages=Pages-1
945 GOSUB Display_page
946 RETURN
947 !
948 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
949 !
950 Header: !
951 PRINT TABXY(1,1)
952 PRINT
953 PRINT TAB(36);"PAGE: ";Page
954 PRINT
955 PRINT USING Head1;"CHAN ID","SIGNAL LABEL","UNITS LABEL","SCALE","STATS"
956 PRINT USING Head2;"(y-axis)","(y-axis)","MIN","MAX","(yes/no)"
957 PRINT
958 RETURN
959 !
960 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
961 !
962 Display_chans: !
963 Plotspage=0
964 PRINT TABXY(1,Firstline+1)
965 FOR Nplot=1 TO Maxplots
966     IF Plotlist$(Page,Nplot)<>"" THEN
967         Plotspage=Plotspage+1
968         Target$=Plotlist$(Page,Nplot)
969         GOSUB Get_channum
970         I=Page
971         J=Nplot
972         PRINT USING Line1;Plotlist$(I,J),Pgsignal$(I,J),Pglabel$(I,J),Scalemin
(I,J),Scalemax(I,J),Pgstat$(I,J)
973     ELSE
974         PRINT USING "80A";""
975     END IF
976 NEXT Nplot
977 IF Prntflag THEN Disp_exit
978 IF Plotlist$(Page,1)<>"" THEN
979     Linenum=Firstline
980     Nplot=1
981     PRINT TABXY(1,Linenum)
982     PRINT CHR$(129)
983     I=Page
984     J=Nplot

```

```

985     PRINT USING Line1;Plotlist$(I,J),Pgsignals$(I,J),Pglabels$(I,J),Scalemin(
I,J),Scalemax(I,J),Pgstat$(I,J)
986     PRINT CHR$(128)
987     END IF
988 Disp_exit: !
989     RETURN
990     !
991     !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
992     !
993 Input_channel: !
994     INPUT "CHANNEL ID?",Plotlist$(Page,Nplot)
995     Target$=Plotlist$(Page,Nplot)
996     GOSUB Get_channum
997     IF NOT Found THEN
998         DISP "CHANNEL ID NOT FOUND IN SCAN CONTROL FILE"
999         WAIT 1
1000        DISP ""
1001        GOTO Input_channel
1002    END IF
1003    INPUT "Y-AXIS SIGNAL LABEL?",Pgsignals$(Page,Nplot)
1004    INPUT "Y-AXIS UNITS LABEL?",Pglabels$(Page,Nplot)
1005    INPUT "Y SCALE MINIMUM,MAXIMUM? enter 0,0 for autoscale",Scalemin(Page,Npl
ot),Scalemax(Page,Nplot)
1006    INPUT "DO STATISTICS ON THIS CHANNEL? enter 1=YES or 0=NO",Stats_flag
1007    Pgstat$(Page,Nplot)="NO"
1008    IF Stats_flag=1 THEN Pgstat$(Page,Nplot)="YES"
1009    RETURN
1010    !
1011    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1012    !
1013 Get_channum: !
1014    Found=0
1015    J=1
1016    LOOP
1017        EXIT IF J>Stop_chan
1018        EXIT IF Target$=Cid$(J)
1019        J=J+1
1020    END LOOP
1021    IF J>Stop_chan THEN Get_chan_exit
1022    Chan=J
1023    Found=1
1024 Get_chan_exit: !
1025    RETURN
1026    !
1027    !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1028    !
1029 Print_table: !
1030    PRINTER IS Pr
1031    Prntflag=1
1032    GOSUB Header
1033    GOSUB Display_chans
1034    PRINTER IS CRT

```

```

1035 Prntflag=0
1036 RETURN
1037 !
1038 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1039 !
1040 Clearkeys: !
1041 FOR Keynum=0 TO 9
1042     ON KEY Keynum LABEL "" GOSUB Dummy
1043 NEXT Keynum
1044 RETURN
1045 !
1046 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1047 !
1048 Dummy: !
1049 RETURN
1050 !
1051 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1052 !
1053 Exit_graphcon: !
1054 PRINT USING "@"
1055 DISP ""
1056 RETURN
1057 !
1058 !
1059 Sub_exit: !
1060 SUBEND
1061 !
1062 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1063 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1064 SUB Confile(Storeflag)
1065 OPTION BASE 1
1066 COM /A110/ Job$,Nm$,Tst$,Run$
1067 COM /A111/ D0$,D1$,W0$,W1$,D2$
1068 COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
1069 COM /A114/ REAL Filt,Ttot,Digdate,Ztime
1070 COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
1071 !
1072 COM /Gph0/ Title$,Plotlist$(*),Pglabel$(*)
1073 COM /Gph1/ Pgstat$(*),Pgsignals$(*)
1074 COM /Gph3/ INTEGER Pages,Datalow(6),Datahigh(6)
1075 COM /Gph4/ REAL Xzer(*),Scalemin(*),Scalemax(*)
1076 !
1077 !                                     CREATE, READ or STORE CONFIG FILE
1078 Jobfile: !
1079 IF Job$<>"" THEN Onerr
1080 INPUT "INPUT JOB# ( <= 4 CHRS )",Job$
1081 Onerr: !
1082 !DISP "PAUSE IN CONFILE ROUTINE"
1083 !PAUSE
1084 ON ERROR GOTO Createfile
1085 ASSIGN @Con TO Job$&"CON"&D0$
1086 IF Storeflag THEN Storefile ! ELSE READ

```



```

1087 DISP "READING CONTROL FILE: ",Job$&"CON"
1088 ENTER @Con,1;Conv(*),Xzer(*),Scalemin(*),Scalemax(*),Hz,Filt,Npts,Ttot,Dig
date,Start_chan,Stop_chan,Outdate,Pages
1089 ENTER @Con,2;Cid(*),Unit(*),Title$,Pgstat$(*)
1090 ENTER @Con,3;Plotlist$(*),Pglabel$(*)
1091 ENTER @Con,4;Pgsignals$(*)
1092 Nchan=Stop_chan-Start_chan+1
1093 OFF ERROR
1094 GOTO Sub_exit
1095 Createfile:|
1096 OFF ERROR
1097 IF ERRN=53 THEN INPUT "PUNCTUATION NOT ALLOWED IN FILENAMES - PRESS 'CONT'
",Zz$
1098 IF ERRN=53 THEN Sub_exit
1099 IF ERRN=80 THEN INPUT "PLACE DISK LEFT DRIVE - PRESS 'CONT'",Zz$
1100 IF ERRN=80 THEN Onerr
1101 IF ERRN<>56 THEN Error_recover
1102 DISP "CREATING JOB CONTROL FILE: ",Job$&"CON"
1103 CREATE BDAT Job$&"CON"&D0$,5,2560
1104 ASSIGN @Con TO Job$&"CON"&D0$
1105 Stop_chan=32
1106 Hz=0
1107 Storefile:|
1108 DISP "STORING JOB PARAMETERS IN CONTROL FILE: ",Job$&"CON"
1109 OUTPUT @Con,1;Conv(*),Xzer(*),Scalemin(*),Scalemax(*),Hz,Filt,Npts,Ttot,Di
gdate,Start_chan,Stop_chan,Outdate,Pages
1110 OUTPUT @Con,2;Cid(*),Unit(*),Title$,Pgstat$(*)
1111 OUTPUT @Con,3;Plotlist$(*),Pglabel$(*)
1112 OUTPUT @Con,4;Pgsignals$(*)
1113 GOTO Sub_exit
1114 Error_recover:|
1115 PRINT USING "@"
1116 PRINT "ERROR #";ERRN
1117 PRINT "YOU ARE CURRENTLY PAUSED IN READ/STORE CONTROL FILE ROUTINE"
1118 PAUSE
1119 Sub_exit:|
1120 SUBEND
1121 |
1122 |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1123 |!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1124 SUB Graph
1125 |
1126 GOSUB Init
1127 GOSUB Graphkeys
1128 GOTO Graphout
1129 |
1130 Init:|
1131 OPTION BASE 1
1132 COM /A110/ Job$,Nm$,Tst$,Run$
1133 COM /A111/ D0$,D1$,W0$,W1$,DZ$
1134 COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Postrun
1135 COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan

```

```

1136 COM /A114/ REAL Filt,Ttot,Digdate,Ztime
1137 COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
1138 !
1139 COM /Gph0/ Title$,Plotlist$(*),Pglabel$(*)
1140 COM /Gph1/ Pgstat$(*),Pgsignal$(*)
1141 COM /Gph2/ INTEGER Zerolow,Zerohigh,PowerZlow,PowerZhigh
1142 COM /Gph3/ INTEGER Pages,Datalow(*),Datahigh(*)
1143 COM /Gph4/ REAL Xzer(*),Scalemin(*),Scalemax(*)
1144 !
1145 COM /Calib/ REAL Slope(*),Intercept(*)
1146 !
1148 ALLOCATE REAL Area(Pages),Real_data(Npts)
1149 ALLOCATE INTEGER Data(Npts)
1150 DIM Str$(25),Fl$(25),Dat$(12)
1151 INTEGER Plt,Page,I,Xx,Nplot,Count,Chan,Target,Maxchans
1152 INTEGER Intervals,Interval,Num_points,First_pnt,Last_pnt,Lowint,Highint
1153 REAL Ireal,Totalarea
1154 GOSUB Graph_params
1155 Maxchans=32
1156 RETURN
1157 !
1158 Graphkeys: !
1159 GRAPHICS OFF
1160 ON KEY 0 LABEL " NEXT RUN" GOSUB Increment_run
1161 ON KEY 1 LABEL "PRINT ZEROS" GOSUB Print_zeroes
1162 ON KEY 2 LABEL "" GOTO Graphkeys
1163 ON KEY 3 LABEL " SET WINDOW" GOSUB Set_window
1164 ON KEY 4 LABEL "" GOTO Graphkeys
1165 ON KEY 5 LABEL " PLOT PAGE" GOSUB Plot_page
1166 ON KEY 6 LABEL "ALL PLOTS & STATS" GOSUB Plot_all
1167 ON KEY 7 LABEL "TRANS AVGS" GOSUB Transkeys
1168 ON KEY 8 LABEL " CHANGE TITLE" GOSUB Change_title
1169 ON KEY 9 LABEL " EXIT" GOTO Keys_return
1170 GOTO Graphkeys
1171 !
1172 Keys_return: !
1173 RETURN
1174 !
1175 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1176 !
1177 Plot_page: !
1178 INPUT "PAGE NUMBER?",Page
1179 IF Page>Pages THEN
1180 DISP "PAGE NOT DEFINED"
1181 WAIT 1
1182 DISP ""
1183 GOTO Plotpg_exit
1184 END IF
1185 Firstpage=Page
1186 Lastpage=Page
1187 GOSUB Plotpages
1188 Plotpg_exit: !

```

```

1189 RETURN
1190 !
1191 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1192 !
1193 Plot_all: !
1194 IF Pages=0 THEN
1195     DISP "NO PAGES DEFINED"
1196     WAIT 1
1197     DISP ""
1198     GOTO Plotall_exit
1199 END IF
1200 Tflag=1
1201 FOR Page_no=1 TO 9
1202     Firstpage=Page_no
1203     Lastpage=Page_no
1204 ! GOSUB Plotpages
1205 ! GOSUB Dump_graph
1206     PRINTER IS 701
1207 ! PRINT USING "@"
1208     PRINTER IS 1
1209 NEXT Page_no
1210 PRINTER IS 701
1211 GOSUB Set_window
1212 FOR Page_no=1 TO 9
1213     Page=Page_no
1214     GOSUB Get_nplot
1215     GOSUB Do_stats
1216     PRINT
1217     PRINT
1218 NEXT Page_no
1219 PRINTER IS 1
1220 Tflag=0
1221 RETURN
1222 !
1223 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1224 Transkeys: !
1225 GRAPHICS OFF
1226 INTEGER No_means, Step_size
1227 Tflag=1 ! SO THAT PLOT_PAGE ROUTINE RETURNS TO TRANSKEYS
1228 Stanflag=0 ! STANFLAG=1 MEANS STANDARD CASE HAS BEEN SELECTED
1229 Max_no=300 ! MAXIMUM NUMBER OF MEANS WHICH CAN BE COMPUTED
1230 ! FOR ARRAY DIMENSIONING
1231 GOSUB Choose_seg! SETS STANFLAG TO 1 AND DOES 3 SEGMENTS IF DESIRED
1232 Ans$="N"
1233 INPUT "IS THE DATA STORED", Ans$
1234 FOR Seg_no=Init_seg TO Last_seg
1235     Seg$=VAL$(Seg_no)
1236     IF Ans$="Y" THEN
1237         GOSUB Get_forces
1238         ALLOCATE Tmean(1), Tpts(1), Trans_mean(1,1) ! SO THEY CAN BE DEALLOCATED
1239     ELSE
1240         IF Stanflag=1 AND Ans$="N" THEN

```

```

1241      GOSUB Tstan ! STANDARD CASE FINDS FORCES AT EVERY .5 SEC OF TIME HIS
1242  ELSE
1243      GOSUB Set_window
1244      GOSUB Clearkeys
1245      GOSUB Tkeys ! SELECT POINTS AT WHICH TO COMPUTE THE MEANS
1246  END IF
1247      GOSUB Dim_plot_arrays ! ALLOCATE PLOT VARIABLES
1248      GOSUB Pos_init ! SELECT SEGMENT PARAMETERS, ALLOCATE MEAN ARRAYS
1249      GOSUB Find_trans_avgs
1250      GOSUB Find_forces
1251      IF Stanflag=1 THEN GOSUB Store_forces
1252  END IF
1253      GOSUB Tplot
1254      PRINTER IS 701
1255      GOSUB Force_stats
1256      IF Stanflag=1 THEN PRINT CHR$(12)
1257      PRINTER IS 1
1258      DEALLOCATE Tpts(*),Trans_mean(*),Tmean(*),X(*),Z(*),Fn(*),Ffrict(*),Phi(
1259  *),Mu(*),Plot_time(*),Psi(*)
1260  Tflag=0
1261  Stanflag=0
1262  RETURN
1263  ! .....
1264  Tkeys: !
1265      ON KEY 1 LABEL "" GOTO Tkeys
1266      ON KEY 2 LABEL "" GOTO Tkeys
1267      ON KEY 3 LABEL "" GOTO Tkeys
1268      ON KEY 4 LABEL "" GOTO Tkeys
1269      ON KEY 5 LABEL "STANDARD",11 GOSUB Tstan
1270      ON KEY 6 LABEL "ONE TIME",11 GOSUB Single_time
1271      ON KEY 7 LABEL "SELECT TIMES",11 GOSUB Select_times
1272      ON KEY 8 LABEL "SELECT FREQUENCY",11 GOTO Sel_mean_int
1273      ON KEY 9 LABEL "EXIT",11 GOTO Tkeys_return
1274      GOTO Tkeys
1275  Tkeys_return: GOSUB Clearkeys
1276  PRINT "NUMBER OF MEANS",No_means
1277  RETURN
1278  ! .....
1279  Dim_plot_arrays: ! ARRAYS FOR THE LFORCE ROUTINE AND PLOTS ARE ALLOCATED
1280  ALLOCATE X(No_means),Z(No_means),Fn(No_means),Ffrict(No_means),Phi(No_means
1281  ),Mu(No_means),Plot_time(No_means),Psi(No_means)
1282  RETURN
1283  ! .....
1283  Choose_seg: ! USER CHOOSES SEGMENT TO BE ANALYSED
1284      INPUT "INPUT SEGMENT TO BE ANALYSED, INPUT 4 FOR ALL 3 SEGMENTS",Seg_no
1285      Init_seg=Seg_no
1286      Last_seg=Seg_no
1287      IF Seg_no=4 THEN
1288          Stanflag=1
1289          Init_seg=1

```

```

1290     Last_seg=3
1291     END IF
1292     RETURN
1293 ! .....
1294 Tpts_select:  ! USER SETS TIMES AND # OF POINTS PER TIME CHOSEN
1295     GOSUB Plot_page
1296     Tj=0
1297 Tresp:  VIEWPORT 12,102,0,100
1298     WINDOW 1,Num_points,0,100
1299     Cur=1
1300     OFF KEY
1301     GOSUB Clearkeys
1302     PEN 0
1303 Tresp_ret:  !
1304     MOVE Cur,100-Topm+4
1305     DRAW Cur,Bot
1306     ON KNOB .1,15 GOTO Tknob_resp
1307     ON KEY 6 LABEL "START POINT",15 GOTO Set_low_point
1308     ON KEY 9 LABEL "  EXIT",15 GOTO Fix_tint_exit
1309     GOTO 1309
1310     !
1311 Tknob_resp:  !
1312     MOVE Cur,100-Topm+4
1313     DRAW Cur,Bot
1314     GOSUB Pulses
1315     GOTO Tresp_ret
1316     !
1317 Fix_tint_exit:  !
1318     PEN 1
1319     GRAPHICS OFF
1320     GOSUB Clearkeys
1321     OFF KNOB
1322     RETURN
1323     !
1324 Set_low_point:  !SETS STARTING POINT FOR MEAN CALCULATION
1325     Tj=Tj+1
1326     GOSUB Get_cur
1327     Tpts(Tj)=INT(Cur)
1328     ! PRINT "TPTS(TJ)",Tpts(Tj)
1329     PEN 0
1330     GOTO Tresp_ret
1331     ! .....
1332 Select_times:  ! SELECT SEVERAL TIMES FROM THE DATA INTERVAL AND
1333                ! SELECT THE POINTS PER MEAN
1334     ALLOCATE Tpts(15)
1335     GOSUB Tpts_select
1336     No_means=Tj
1337 ! PRINT "FIRST POINT  ",Tpts(1)+First_pnt
1338     FOR I=1 TO No_means
1339         Tpts(I)=Tpts(I)+First_pnt-1
1340     NEXT I
1341     INPUT "ENTER THE NUMBER OF POINTS PER MEAN CALCULATION",Pts_per_mean

```

```

1342 RETURN
1343 ! .....
1344 Single_time: !
1345 INPUT "DO CALCULATIONS OVER HOW MANY SECOND",Nsecs
1346 Max_no=Hz*Nsecs
1347 ALLOCATE Tpts(Max_no)
1348 No_means=Max_no
1349 PRINT " NUMBER OF SAMPLES =",Max_no
1350 GOSUB Tpts_select
1351 Tpts(1)=Tpts(1)+First_pnt-1
1352 FOR J=2 TO Max_no
1353     Tpts(J)=Tpts(1)+J
1354 NEXT J
1355 Pts_per_mean=1
1356 Stanflag=1
1357 RETURN
1358 ! .....
1359 Sel_mean_int: ! SELECT FREQUENCY AT WHICH MEANS ARE TO BE CALCULATED
1360 INPUT "HOW MANY MEANS PER DATA INTERVAL",No_means
1361 INPUT "HOW MANY DATA POINTS PER MEAN",Pts_per_mean
1362 Step_size=INT((Last_pnt-First_pnt)/(No_means+1))+1
1363 ALLOCATE Tpts(No_means)
1364 FOR J=1 TO No_means
1365     Tpts(J)=First_pnt+J*Step_size
1366 NEXT J
1367 GOTO Tkeys_return
1368 ! .....
1369 Tstan: ! STANDARD CASE
1370 Stanflag=1
1371 Step_size=INT(.5*Hz) ! FIND THE MEAN EVERY .5 SEC
1372 No_means=INT((Last_pnt-First_pnt)/Step_size)
1373 IF No_means>Max_no THEN No_means=Max_no
1374 PRINT "NUMBER OF MEANS IS ",No_means
1375 ALLOCATE Tpts(No_means)
1376 Pts_per_mean=2
1377 FOR J=1 TO No_means
1378     Tpts(J)=First_pnt+J*Step_size
1379 NEXT J
1380 RETURN
1381 ! .....
1382 Find_trans_avgs: ! CALCULATES THE AVERAGE MEASUREMENT FO EACH TRANSDUCER
1383 PRINT " TIME ";
1384 FOR Chan=Firstchan TO Lastchan
1385     K=Chan-Firstchan+1
1386     PRINT USING Chanlabel;Cid$(Chan) ! CHANNEL NAME
1387     GOSUB Get_trans_data
1388     GOSUB Do_conversion
1389     FOR J=1 TO No_means
1390         Mean=0
1391         FOR L=1 TO Pts_per_mean
1392             Mean=Mean+Real_data(Tpts(J)+L-1)
1393         NEXT L

```



```

1394     Trans_mean(K,J)=Mean/Pts_per_mean
1395     NEXT J
1396     NEXT Chan
1397 ! PRINTER IS 701
1398     FOR J=1 TO No_means
1399         PRINT
1400         Plot_time(J)=(Tpts(J)+(Pts_per_mean-1)/2)/Hz
1401         PRINT USING Transfor;Plot_time(J)
1402         FOR I=1 TO Ntrans
1403             PRINT USING Transfor;Trans_mean(I,J)
1404         NEXT I
1405     NEXT J
1406     PRINT
1407 Chanlabel:     IMAGE 4A,3X,#
1408 Transfor:     IMAGE 0DD.D,2X,#
1409     RETURN
1410 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1411 Find_forces:    ! FINDS NORMAL FORCE, FRICTION FORCE AND LOCATION OF EACHG
1412     Ps="N"
1413     IF Stanflag=0 THEN INPUT " DO YOU WANT HARDCOPY (Y/N)",Ps
1414     IF Ps="Y" THEN PRINTER IS 701
1415     PRINT
1416     PRINT USING Label3for;"FILE NAME",Nm$,"MEAN CALCULATED OVER",Pts_per_m
ean/Hz," SECS"
1417     PRINT
1418     PRINT USING Label1for;"TIME","NORMAL","LOCATION(M)","ANGLES","FRICT.",
"FRICT.","FRICT. ANGLES"
1419     PRINT USING Label2for;"FORCE","X","Z","ALPHA","BETA","FORCE","COEFF.",
"NOR PROJ"
1420     K=0
1421     FOR J=1 TO No_means
1422         FOR I=1 TO Ntrans
1423             Tmean(I)=Trans_mean(I,J)*Corr_fact(I)
1424         NEXT I
1425 ! INPUT "ENTER TRANSDUCER INPUTS",Tmean(1),Tmean(2),Tmean(3),Tmean(4),Tmean(5
),Tmean(6),Tmean(7),Tmean(8)
1426     GOSUB Trans_reduce
1427 ! INPUT "ENTER RT,HT,VT",Rt,Ht,Vt      ! FOR DEBUGGING
1428 ! INPUT "ENTER C1,C2,C3",C1,C2,C3      ! FOR DEBUGGING
1429 ! INPUT "ENTER XORIGIN",Xorigin
1430     IF Totfor>Fcutoff THEN !AND Tmean(4)>0 THEN      ! IF Fn>8 THEN To
tal Force IS > 8
1431     CALL Lforce(Rt,Ht,Vt,C1,C2,C3,Seg_no,Xorigin,Fn(J),Ffrictt,Mut,Xt,
Zt,Alpha,Beta,Phit,Psit,Segflag)
1432     IF Segflag=0 THEN
1433         PRINT USING Outfor;Plot_time(J),Fn(J),Xt,Zt,Alpha,Beta,Ffrictt,M
ut,Phit,Psit
1434 !     K=K+1
1435         X(J)=Xt
1436         Z(J)=Zt
1437         Mu(J)=Mut
1438         Ffrict(J)=Ffrictt

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```

1439         Phi(J)=Phit
1440         Psi(J)=Psit
1441     ELSE
1442         GOSUB Null_values
1443     END IF
1444 ELSE
1445     GOSUB Null_values
1446 END IF
1447 NEXT J
1448 Label1for: IMAGE 5A,2X,6A,2X,11A,2X,9A,2X,6A,2X,6A,2X,13A
1449 Label2for: IMAGE 7X,6A,4X,6A,4A,6A,4A,2X,6A,2X,6A,2X,13A
1450 Label3for: IMAGE 12A,6A,2X,22A,D.DDD
1451 Outfor: IMAGE DDD.DD,2X,DDD.D,3X,D.DDD,1X,D.DDD,2X,DD.D,DDD.D,2X,DDD.D,3X,D
D.DD,3X,DDDD.,3X,DDDD.
1452 PRINTER IS 1
1453 RETURN
1454 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1455 Null_values: ! PUTS NULL VALUES INTO X,Z,Ff,Mu,Phi,Psi IF THE SUBROUTINE
1456             ! CAN'T LOCATE THE FORCE OR THE FORCE IS TOO SMALL
1457     Fn(J)=Totfor/1.044
1458     Ffrict(J)=0
1459     X(J)=0
1460     Z(J)=-.01
1461     Mu(J)=0
1462     Phi(J)=-180
1463     Psi(J)=-180
1464     PRINT USING Outfor3;Plot_time(J),Fn(J)
1465 Outfor3: IMAGE DDD.DD,2X,DDD.D
1466 RETURN
1467 !.....
1468 !
1469 Pos_init: ! INITIALIZES X,Y,AND Z POSITIONS OF TRANSDUCERS
1470     DIM Xpos(12),Ypos(12),Zpos(12),Corr_fact(12)
1471     ALLOCATE Trans_mean(12,Max_no),Tmean(12)
1472     SELECT Seq_no
1473     CASE 1
1474         Ntrans=8
1475         Firstchan=1
1476         Hfirst=2
1477         Hlast=3
1478         Xorigin=2.0
1479         Fcutoff=5
1480         DATA 0.,.050,.020,1.0 ! R11 POSITION
1481         DATA 2.219,0.,.020, 1.0 ! H11 POSITION
1482         DATA 2.055,0.,.083, 1.0 ! H12 POSITION
1483         DATA 2.255,.025,0, .86 ! V11 POSITION
1484         DATA 2.056, .153,0, .86 ! V12 POSITION
1485         DATA 2.165, .02, 0, .86 ! V13 POSITION
1486         DATA 2.16,.05,.02, .86603 ! RV1 POSITION,CORR FCT ACCOUNTS FOR ANGLE
1487         DATA 2.137,.05,.05,.7071 ! HV1 POSITION,CORR FCT ACCOUNTS FOR ANGLE
1488     RESTORE 1480
1489     CASE 2

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1542      Rt=Rt+Tmean(I)
1543      Rysum=Rysum+Tmean(I)*Ypos(I)
1544      Rzsum=Rzsum+Tmean(I)*Zpos(I)
1545      NEXT I
1546      FOR I=Hfirst TO Hlast
1547          Ht=Ht+Tmean(I)
1548          Hxsum=Hxsum+Tmean(I)*Xpos(I)
1549          Hzsum=Hzsum+Tmean(I)*Zpos(I)
1550      NEXT I
1551      FOR I=Hlast+1 TO Ntrans
1552          Vt=Vt+Tmean(I)
1553          Vxsum=Vxsum+Tmean(I)*Xpos(I)
1554          Vysum=Vysum+Tmean(I)*Ypos(I)
1555      NEXT I
1556      SELECT Seg_no          ! FOR FRICTION CORRECTIONS
1557      CASE 1
1558          GOSUB Seg1
1559      ! CASE 2
1560      !   Rt=Rt+.11*Vt+.11*Ht    ! ADD FRICTION OF VERTICAL AND HORZ LOAD CELLS
1561      !   Rzsum=Rzsum+.11*Hzsum
1562      !   Rysum=Rysum+.11*Vysum+.11*Hysum
1563      END SELECT
1564      Totfor=SQR(Rt*Rt+Ht*Ht+Vt*Vt)
1565      C1=Hzsum-Vysum
1566      C2=Vxsum-Rzsum
1567      C3=Rysum-Hxsum
1568      PRINT
1569      ! PRINT Rt,Ht,Vt,"SUM OF FORCES"
1570      ! PRINT C1,C2,C3,"MOMENTS IN PLANES"
1571      RETURN
1572      ! .....
1573      Tplot: ! PLOTS RESULTS OF DATA REDUCTION ALGORITHM
1574      INTEGER I0,I1,I2,Repeat,Plottype,Opt1,Opt2,Hard,Screen,Popt
1575      DIM T1$(40)
1576      T1$=Tst$&" RUN "&Run$&" SEGMENT "&Seg$&" "&Dat$
1577      Tx$=" SECONDS"
1578      Plottype=0      ! LINEAR PLOT
1579      Opt1=1          ! HOW POINTS ARE PLOTTED: CONNECTED BY A CONT. LINE
1580      Opt2=1          ! TYPE OF GRID LINES :SHORT LINES
1581      Mint=Plot_time(1)
1582      Maxt=Mint
1583      Ttick=0
1584      I0=1
1585      I2=No_means
1586      I1=No_means
1587      Hard=2      ! HARD=2 FOR HARDCOPY PROMT, HARD=21 FOR AUTOMATIC HARDCOPY
1588      Screen=0
1589      Popt=1
1590      REPEAT
1591      IF Stanflag=1 THEN
1592          Plotans=1
1593      ELSE

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1594 PRINT "QUIT ..... ENTER 0"
1595 PRINT "PLOT ALL PARAMETERS ENTER 1"
1596 PRINT "PLOT FORCES ..... ENTER 2"
1597 PRINT "PLOT POSITIONS .... ENTER 3"
1598 PRINT "PLOT PHI ..... ENTER 4"
1599 PRINT "PLOT MU ..... ENTER 5"
1600 INPUT "ENTER CHOICE",Plotans
1601 END IF
1602 SELECT Plotans
1603 CASE 1
1604     GOSUB Plot_forces
1605     GOSUB Plot_position
1606     PRINTER IS 701
1607     IF Stanflag=1 THEN PRINT USING "@"
1608     PRINTER IS 1
1609     GOSUB Plot_phi
1610     GOSUB Plot_mu
1611 CASE 2
1612     GOSUB Plot_forces
1613 CASE 3
1614     GOSUB Plot_position
1615 CASE 4
1616     GOSUB Plot_phi
1617 CASE 5
1618     GOSUB Plot_mu
1619 END SELECT
1620 IF Stanflag=1 THEN Plotans=0
1621 UNTIL Plotans=0
1622 RETURN
1623 ! .....
1624 Plot_forces:      ! CALLS SUBROUTINE TO PLOT NORMAL AND FRICTION FORCES
1625 Fmin=0
1626 SELECT Seq_no
1627 CASE 1
1628     Fmax=40
1629     Ftick=10
1630 CASE 2
1631     Fmax=50
1632     Ftick=10
1633 CASE 3
1634     Fmax=175
1635     Ftick=25
1636 END SELECT
1637 Fnull=0
1638 Ffnull=0
1639 T2$="SEGMENT FORCES"
1640 Ty$="Newtons"
1641 CALL Xyplot(Plot_time(*),Fn(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Fmin,Fmax,
Ftick,Fnull,I0,I1,0,Plotttype,Opt1,Opt2,Screen)
1642 CALL Xyplot(Plot_time(*),Ffrict(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Fmin,F
max,Ftick,Ffnull,I0,I2,1,Plotttype,Opt1,Opt2,Screen)
1643 CALL Xyplot(Plot_time(*),Ffrict(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Fmin,F

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max,Ftick,Ffnull,I0,I2,1,Plottype,Popt,Opt2,Hard)
1644 GRAPHICS OFF
1645 RETURN
1646 ! .....
1647 Plot_position: ! CALLS SUBROUTINE TO PLOT X AND Z COORDINATES OF THE
1648 ! NORMAL FORCE
1649 SELECT Seg_no
1650 CASE 1
1651     Xmax=2.42
1652     Xmin=2.02
1653 CASE 2
1654     Xmax=2.03
1655     Xmin=1.61
1656 CASE 3
1657     Xmax=1.63
1658     Xmin=.88
1659 END SELECT
1660 Xtick=.1
1661 Xnull=0.
1662 T2$="X POSITION"
1663 Ty$="Meters"
1664 CALL Xyplot(Plot_time(*),X(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Xmin,Xmax,X
tick,Xnull,I0,I2,0,Plottype,Opt1,Opt2,Screen)
1665 CALL Xyplot(Plot_time(*),X(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Xmin,Xmax,X
tick,Xnull,I0,I2,1,Plottype,Popt,Opt2,Hard)
1666 Zmin=-.16
1667 Zmax=0.
1668 Ztick=.02
1669 Znull=.01
1670 ALLOCATE Zp(No_means)
1671 FOR I=1 TO No_means
1672     Zp(I)=-Z(I)
1673 NEXT I
1674 T2$="Z POSITION"
1675 Ty$="Meters"
1676 CALL Xyplot(Plot_time(*),Zp(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Zmin,Zmax,
Ztick,Znull,I0,I2,0,Plottype,Opt1,Opt2,Screen)
1677 CALL Xyplot(Plot_time(*),Zp(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Zmin,Zmax,
Ztick,Znull,I0,I2,1,Plottype,Popt,Opt2,Hard)
1678 DEALLOCATE Zp(*)
1679 GRAPHICS OFF
1680 RETURN
1681 ! .....
1682 Plot_phi: ! CALLS SUBROUTINE TO PLOT THE FRICTION DIRECTION FROM
1683 ! THE HORIZONTAL PHI--NORMAL, PSI--PROJECTED
1684 Phimin=-180
1685 Phimax=180
1686 Phitick=45
1687 Phinull=-180
1688 T2$="FRICTION DIRECTION"
1689 Ty$="Degrees"
1690 ! CALL Xyplot(Plot_time(*),Phi(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Phimin,Ph

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imax,Phitick,Phinull,I0,I2,0,Plotttype,Opt1,Opt2,Screen)
1691 CALL Xyplot(Plot_time(*),Psi(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Phimin,Ph
imax,Phitick,Phinull,I0,I2,0,Plotttype,Popt,Opt2,Screen)
1692 CALL Xyplot(Plot_time(*),Psi(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Phimin,Ph
imax,Phitick,Phinull,I0,I2,1,Plotttype,Popt,Opt2,Hard)
1693 GRAPHICS OFF
1694 RETURN
1695 ! .....
1696 Plot_psi: ! CALLS SUBROUTINE TO PLOT PSI (PROJECTED FRICTION DIR)
1697 Plot_mu: ! CALLS SUBROUTINE TO PLOT THE FRICTION COEFFICIENT
1698 Mumin=0.
1699 Mumax=1.0
1700 Mutick=.10
1701 Munull=0
1702 T2$="FRICTION COEFF"
1703 Ty$=""
1704 CALL Xyplot(Plot_time(*),Mu(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Mumin,Muma
x,Mutick,Munull,I0,I2,0,Plotttype,Opt1,Opt2,Screen)
1705 CALL Xyplot(Plot_time(*),Mu(*),T1$,T2$,Tx$,Ty$,Mint,Maxt,Ttick,Mumin,Muma
x,Mutick,Munull,I0,I2,1,Plotttype,Popt,Opt2,Hard)
1706 GRAPHICS OFF
1707 RETURN
1708 ! .....
1709 Force_stats: ! IF STATISTICS ARE WANTED A SUBROUTINE IS CALLED
1710 INTEGER No_reapts
1711 Statans$="Y"
1712 IF Stanflag=0 THEN INPUT "DO YOU WANT STATS ON SEG FORCES (Y/N)",Statans$
1713 IF Statans$="Y" THEN
1714 Seg$=VAL$(Seg_no)
1715 INPUT "ENTER INIT AND FINAL TIME FOR STATISTIC CALCULATIONS",Itime,Ltime
1716 PRINT USING Label4;"STATISTICS FOR INTERVAL FROM ",Itime," TO ",Ltime," S
econds"
1717 PRINT USING Label5for;"SAMPLES CALCULATED EVERY",(Plot_time(No_means)-Plo
t_time(1))/No_means," SECS"
1718 PRINT "TEST",Tst$,"RUN",Run$,"DATE:",Dat$
1719 PRINT "SEGMENT ",Seg$
1720 PRINT
1721 CALL Average(Fn(*),2.0,Plot_time(*),Itime,Ltime,Favg,Fdev,No_means,No_rea
lpts)
1722 PRINT USING Outfor4;"AVERAGE NORMAL FORCE",Favg,"STANDARD DEVIATION",Fdev
1723 PRINT
1724 CALL Average(X(*),Xmin,Plot_time(*),Itime,Ltime,Xavg,Xdev,No_means,No_rea
lpts)
1725 PRINT USING Outfor4;"AVERAGE X POSITION",Xavg,"STANDARD DEVIATION",Xdev
1726 PRINT
1727 CALL Average(Z(*),-.01,Plot_time(*),Itime,Ltime,Zavg,Zdev,No_means,No_rea
lpts)
1728 PRINT USING Outfor4;"AVERAGE Z POSITION",Zavg,"STANDARD DEVIATION",Zdev
1729 PRINT
1730 CALL Average(Mu(*),0,Plot_time(*),Itime,Ltime,Muavg,Mudev,No_means,No_rea
lpts)
1731 PRINT USING Outfor4;"AVERAGE FRICTION COEFF",Muavg,"STANDARD DEVIATION",M

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udev
1732 I PRINT
1733 I CALL Average(Phi(*),-180,Plot_time(*),Itime,Ltime,Phiavg,Phidev,No_means,
NO_REALPTS)
1734 I PRINT USING Outfor4;"AVERAGE FRICTION DIR.",Phiavg,"STANDARD DEVIATION",P
hidev
1735 PRINT
1736 CALL Average(Psi(*),-180,Plot_time(*),Itime,Ltime,Psiavg,Psidev,No_means,
No_realpts)
1737 PRINT USING Outfor4;"PROJECTED FRICT. DIR.",Psiavg,"STANDARD DEVIATION",P
sidev
1738 PRINT
1739 PRINT USING "45A,DDD";"NUMBER OF DATA POINTS USED IN STATISTICS:",No_real
pts
1740 PRINT
1741 PRINT
1742 END IF
1743 Label4: IMAGE 30A,DDD.DD,4A,DDD.DD,8A
1744 Label5for: IMAGE 27A,0.DDD,6A
1745 Outfor4: IMAGE 25A,DDDD.DDD,5X,20A,DDDD.DDD,8A
1746 RETURN
1747 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1748 Seg1: I ADDS TENSION LINK MEASUREMENTS IN X AND Y DIRECTIONS
1749 R12=Tmean(7)*.57735
1750 H13=Tmean(8)
1751 Rt=Rt+R12
1752 Rysum=Rysum+R12*Ypos(7)
1753 Rzsum=Rzsum+R12*Zpos(7)
1754 Ht=Ht+H13
1755 Hxsum=Hxsum+H13*Xpos(8)
1756 Hzsum=Hzsum+H13*Zpos(8)
1757 RETURN
1758 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1759 Get_forces: I RETREIVES PLOT ARRAYS FROM STANDARD RUNS
1760 PRINT "DATA INTERVAL MUST BE SET TO WHOLE"
1761 Step_size=INT(.5*Hz)
1762 No_means=INT((Last_pnt-First_pnt)/Step_size)
1763 ALLOCATE Fn(No_means),Ffrict(No_means),X(No_means),Z(No_means),Mu(No_mean
s),Phi(No_means),Plot_time(No_means),Psi(No_means)
1764 File$=Tst$&Run$&"SEG"&Seg$&":704,1"
1765 ASSIGN @Forcedata TO File$
1766 ENTER @Forcedata;Fn(*),Ffrict(*),X(*),Z(*),Mu(*),Phi(*),Plot_time(*)
1767 ENTER @Forcedata;Psi(*)
1768 RETURN
1769 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1770 Store_forces: I STORES FORCES FROM STANDARD REDUCTION RUNS
1771 Ans$="N"
1772 INPUT "DO YOU WANT TO STORE THIS FORCE RUN",Ans$
1773 IF Ans$="Y" THEN
1774 File$=Tst$&Run$&"SEG"&Seg$&":704,1"
1775 CREATE BDAT File$,8,8*No_means
1776 ASSIGN @Forcedata TO File$

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1777      OUTPUT @Forcedata;Fn(*),Ffrict(*),X(*),Z(*),Mu(*),Phi(*),Plot_time(*),
Psi(*)
1778      PRINT "NO_MEANS=",No_means
1779      END IF
1780 RETURN
1781 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1782 Change_title: !
1783 GRAPHICS OFF
1784 INPUT "NEW TITLE?",Title$
1785 RETURN
1786 !
1787 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1788 !
1789 Increment_run: !
1790 Run=VAL(Run$)
1791 Run=Run+1
1792 Run$=VAL$(Run)
1793 Nm$=Tst$&Run$
1794 Storeflag=0
1795 DEALLOCATE Data(*),Real_data(*)
1796 CALL Runread(Storeflag)
1797 INPUT "ENTER NPTS",Npts
1798 ALLOCATE INTEGER Data(Npts)
1799 ALLOCATE Real_data(Npts)
1800 GOSUB Graph_params
1801 RETURN
1802 !
1803 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1804 !
1805 Print_zeroes: ! PRINTS OUT THE ZEROES AS CALCULATED BY CALCZEROES
1806 ! INPUT "DO YOU WANT A HARDCOPY (Y/N)",Pansw$
1807 ! IF Pansw$="Y" THEN PRINTER IS 701
1808 FOR Chan=Start_chan TO Stop_chan
1809     Conv_fact=Conv(Chan)*5/2048
1810     PRINT "CHANNEL ID ",Cid$(Chan),"ZERO VALUE ",Xzer(Chan)*Conv_fact
1811 NEXT Chan
1812 ! PRINTER IS 1
1813 ! CONTROL 1,12,2
1814 RETURN
1815 !
1816 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1817 !
1818 Set_window: !
1819 GRAPHICS OFF
1820 GOSUB Clearkeys
1821 DISP "SELECT SECTION OF DATA SET FOR STATISTICS AND/OR TO GRAPH"
1822 ON KEY 5 LABEL " WHOLE",15 GOTO Whole
1823 ON KEY 6 LABEL " DATA INTERVAL",15 GOTO Interval
1824 ON KEY 7 LABEL " POWER2 WINDOW",15 GOTO Power2
1825 Wait_for_key: !
1826 GOTO Wait_for_key
1827 !

```

```

1828 Whole: !
1829 First_pnt=1
1830 Last_pnt=Npts
1831 GOTO Set_window_exit
1832 Interval: !
1833 INPUT "ENTER STATS WINDOW NUMBER TO GRAPH",Interval
1834 First_pnt=DataLow(Interval)
1835 Last_pnt=DataHigh(Interval)
1836 !PRINT "FIRST POINT IS",First_pnt
1837 !PRINT "LAST POINT IS",Last_pnt
1838 GOTO Set_window_exit
1839 Power2: !
1840 First_pnt=Power2Low
1841 Last_pnt=Power2High
1842 GOTO Set_window_exit
1843 !
1844 Set_window_exit: !
1845 Num_points=Last_pnt-First_pnt+1
1846 Tmax=Last_pnt/Hz
1847 Tmin=First_pnt/Hz
1848 Tinc=(Tmax-Tmin)/10
1849 DISP ""
1850 GOSUB Clearkeys
1851 RETURN
1852 !
1853 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1854 !
1855 Graph_params: !
1856 Tmax=Npts/Hz
1857 Tmin=1/Hz
1858 Tinc=(Tmax-Tmin)/10
1859 First_pnt=1
1860 Last_pnt=Npts
1861 Num_points=Last_pnt-First_pnt+1
1862 Lowint=0
1863 Highint=0
1864 Topm=12      ! AREA OF TOP MARGIN FOR GRAPH
1865 Botm=8       ! AREA OF BOT MARGIN FOR GRAPH
1866 RETURN
1867 !
1868 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1869 !
1870 Plotpages: !
1871 FOR Page=Firstpage TO Lastpage
1872     GOSUB Get_nplot
1873     GOSUB Page_init
1874     GOSUB Time_scale
1875     FOR Plot=1 TO Nplot
1876         GOSUB Get_channum
1877         IF NOT Found THEN 1882
1878         GOSUB Get_data
1879         GOSUB Do_conversion

```

```

1880      GOSUB Do_title
1881      GOSUB Do_plot
1882      NEXT Plot
1883      IF Tflag=1 THEN
1884          GOSUB Draw_interval
1885          GOTO Pl_exit
1886      ELSE
1887          GOSUB Keys2
1888      END IF
1889  NEXT Page
1890 Pl_exit: !
1891  RETURN
1892  !
1893  RETURN
1894  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1895  !
1896 Get_nplot: !
1897  Nplot=0          ! # plots on page
1898  I=1
1899  WHILE I<6
1900      IF Plotlist$(Page,I)<>"" THEN Nplot=Nplot+1
1901      I=I+1
1902  END WHILE
1903  Totalarea=100-Topm-Botm-(Nplot-1)
1904  Area(Page)=Totalarea/Nplot          ! area for each plot
1905  RETURN
1906  !
1907  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1908  !
1909 Page_init: !
1910  ALPHA OFF
1911  GRAPHICS ON
1912  GCLEAR
1913  GINIT
1914  RETURN
1915  !
1916  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1917  !
1918 Do_plot: !
1919  GOSUB Plot_where
1920  GOSUB Find_scale
1921  GOSUB Scale_label
1922  GOSUB Plot_points
1923  GOSUB Info_label
1924  GOSUB Div_lines
1925  GOSUB Time_lines
1926  RETURN
1927  !
1928  !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1929  !
1930 Plot_where: ! PUT PLOT WHERE ON THE PAGE
1931  Top=(100-Topm)-(Plot-1)*(Area(Page))-(Plot-1)

```

```

1932 Bot=Top-Area(Page)
1933 VIEWPORT 12,102,Bot,Top
1934 LINE TYPE 1
1935 FRAME
1936 RETURN
1937 !
1938 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1939 !
1940 Get_channum: !
1941 Target=1
1942 Found=0
1943 WHILE Target<=Maxchans
1944     IF Plotlist$(Page,Plot)=Cid$(Target) THEN
1945         Chan=Target
1946         Found=1
1947     END IF
1948     Target=Target+1
1949 END WHILE
1950 RETURN
1951 !
1952 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1953 !
1954 Get_data: !
1955 ASSIGN @Datain TO Nm$&Plotlist$(Page,Plot)&D1$
1956 ENTER @Datain;Data(*)
1957 ASSIGN @Datain TO *
1958 RETURN
1959 !
1960 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1961 !
1962 Get_trans_data: ! GETS DATA FOR TRANS_AVGS
1963 ASSIGN @Datain TO Nm$&Cid$(Chan)&D1$
1964 ENTER @Datain;Data(*)
1965 ASSIGN @Datain TO *
1966 RETURN
1967 !
1968 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1969 !
1970 Do_conversion:!
1971 Conv_fact=Conv(Chan)
1972 Zerolevel=Xzer(Chan)
1973 FOR I=First_pnt TO Last_pnt
1974     Real_data(I)=(Data(I)-Zerolevel)*Conv_fact*5/2048
1975 NEXT I
1976 RETURN
1977 !
1978 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1979 !
1980 Find_scale: ! GET GRAPH SCALE
1981 Min=Scalemin(Page,Plot)
1982 Max=Scalemax(Page,Plot)
1983 CALL Linscale(Real_data(*),Min,Max,Incr,First_pnt,Last_pnt)

```



```

1984 RETURN
1985 !
1986 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1987 !
1988 Plot_points: !
1989 WINDOW 1,Num_points,Min,Max
1990 J=First_pnt
1991 MOVE 1,Real_data(J)
1992 FOR I=2 TO Num_points
1993     J=J+1
1994     PLOT I,Real_data(J)
1995 NEXT I
1996 RETURN
1997 !
1998 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
1999 !
2000 Do_title: !
2001 CSIZE 4
2002 VIEWPORT 12,102,0,100
2003 WINDOW 0,133,0,100
2004 MOVE 66.5,95
2005 LONG 6
2006 LABEL Title$
2007 CLIP OFF
2008 MOVE 148,95
2009 CSIZE 3
2010 LABEL "TEST: ";Tst$
2011 LABEL "RUN: ";Run$
2012 CLIP ON
2013 RETURN
2014 !
2015 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2016 !
2017 Scale_label: !
2018 VIEWPORT 12,102,Bot,Top
2019 WINDOW 0,10,Min,Max
2020 CSIZE 3.2
2021 LINE TYPE 1
2022 LDIR 0
2023 LONG 8
2024 CLIP OFF
2025 FOR Ireal=Min+Incr TO Max-Incr STEP Incr
2026     IF Ireal>0 AND Ireal<.00000001 THEN Ireal=0
2027     MOVE -.03,Ireal
2028     LABEL Ireal
2029     MOVE 0,Ireal
2030     DRAW .1,Ireal
2031 NEXT Ireal
2032 CLIP ON
2033 RETURN
2034 !
2035 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

```

```

2036 !
2037 Info_label:|
2038 VIEWPORT 0,133,Bot,Top
2039 WINDOW 0,133,0,10
2040 CSIZE 4
2041 LDIR 0
2042 LINE TYPE 1
2043 LORG 2
2044 MOVE 104,8
2045 LABEL Pgsignal$(Page,Plot)
2046 MOVE 104,6
2047 LABEL Pglabel$(Page,Plot)
2048 MOVE 104,4
2049 RETURN
2050 !
2051 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2052 !
2053 Div_lines:|
2054 LINE TYPE 4,10
2055 VIEWPORT 0,133,0,100
2056 WINDOW 0,133,0,100
2057 MOVE 0,Bot
2058 DRAW 10,Bot
2059 MOVE 100,Bot
2060 DRAW 133,Bot
2061 LINE TYPE 1
2062 RETURN
2063 !
2064 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2065 Time_scale: !FIND A NICE SCALE FOR THE TIME AXIS
2066 DIM Tsteps(8)
2067 DATA .1,.2,.5,1,2,5,10,20
2068 RESTORE 2067
2069 READ Tsteps(*)
2070 I=1
2071 REPEAT
2072   I=I+1
2073 UNTIL (Tinc>=Tsteps(I-1) AND Tinc<Tsteps(I)) OR (I=8)
2074 IF Tinc<Tsteps(1) THEN I=1
2075 Tinc=Tsteps(I)
2076 Tmaxplot=(INT((Tmax+Tinc)/Tinc)-1)*Tinc
2077 Tminplot=(INT((Tmin+Tinc)/Tinc))*Tinc
2078 RETURN
2079 ! .....
2080 Time_lines:|
2081 VIEWPORT 12,102,0,100
2082 WINDOW Tmin*Hz,Tmax*Hz,0,100
2083 CSIZE 2
2084 LORG 4
2085 LDIR 0
2086 LINE TYPE 1
2087 CLIP OFF

```

```

2088 FOR Ireal=Tminplot TO Tmaxplot STEP Tinc
2089     MOVE Ireal*Hz,Bot
2090     LABEL "!"
2091 NEXT Ireal
2092 IF Plot=Nplot THEN
2093     CSIZE 3
2094     LOG 6
2095     FOR Ireal=Tminplot TO Tmaxplot STEP Tinc
2096         MOVE Ireal*Hz,Bot
2097         IF Ireal<10 THEN LABEL USING "DD.D";Ireal
2098         IF Ireal>=10 THEN LABEL USING "DDD.D";Ireal
2099     NEXT Ireal
2100     CSIZE 3
2101     VIEWPORT 0,133,0,100
2102     WINDOW 0,133,0,100
2103     LOG 3
2104     MOVE 107,Bot
2105     LABEL "SECONDS"
2106 END IF
2107 RETURN
2108 !
2109 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2110 Draw_interval:  IF TFALG =1 THEN LINES FOR DATA INTERVAL 1 ARE DRAWN
2111     VIEWPORT 12,102,0,100
2112     WINDOW Tmin*Hz,Tmax*Hz,0,100
2113     LINE TYPE 1
2114     MOVE Datalow(1),100-Topm+4
2115     DRAW Datalow(1),Bot
2116     MOVE Datahigh(1),100-Topm+4
2117     DRAW Datahigh(1),Bot
2118     VIEWPORT 0,133,0,100
2119     WINDOW 0,133,0,100
2120 RETURN
2121 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2122 !
2123 Keys2: !
2124 ON KEY 0 LABEL "" GOTO Keys2
2125 ON KEY 1 LABEL "" GOTO Keys2
2126 ON KEY 2 LABEL "" GOTO Keys2
2127 ON KEY 3 LABEL "" GOTO Keys2
2128 ON KEY 4 LABEL "" GOTO Keys2
2129 ON KEY 5 LABEL "SET INTERVALS",10 GOSUB Set_intervals
2130 ON KEY 6 LABEL " SET WINDOW",10 GOSUB Set_window
2131 ON KEY 7 LABEL "THINK JET DUMP",10 GOSUB Dump_graph
2132 ON KEY 8 LABEL " STATISTICS",10 GOSUB Do_stats
2133 ON KEY 9 LABEL " EXIT",10 GOTO Keys2_return
2134 GOTO Keys2
2135 !
2136 Keys2_return: !
2137 GOSUB Clearkeys
2138 RETURN
2139 !

```

```

2140 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2141 !
2142 Clearkeys: !
2143 FOR Keynum=0 TO 9
2144     ON KEY Keynum LABEL "" GOSUB Dummy
2145 NEXT Keynum
2146 RETURN
2147 !
2148 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2149 !
2150 Dummy: !
2151 RETURN
2152 !
2153 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2154 !
2155 Dump_graph: !
2156 DUMP DEVICE IS 701,EXPANDED
2157 DUMP GRAPHICS
2158 RETURN
2159 !
2160 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2161 !
2162 Do_stats: ! MIN,MAX,MEAN AND SD BETWEEN INTERVALS
2163 GRAPHICS OFF
2164 ALPHA ON
2165 ALLOCATE REAL Xsd(Nplot),Xav(Nplot)
2166 ALLOCATE Xmx(Nplot),Xmn(Nplot)
2167 IF Tflag=0 THEN GOSUB Set_window ! AUTOMATICALLY CHOOSES THE FIRST WINDOW
2168 FOR Plot=1 TO Nplot
2169     IF Pgstat$(Page,Plot)="NO" THEN Nexti
2170     GOSUB Get_channum
2171     DISP "Reading Data"
2172     GOSUB Get_data
2173     GOSUB Do_conversion
2174     DISP " Computing Statistics For Channel: ";Pgsignal$(Page,Plot)
2175     I=Plot
2176     Xmx(I)=-9^99
2177     Xmn(I)=9^99
2178     Mean=0
2179     FOR J=First_pnt TO Last_pnt
2180         IF Real_data(J)>Xmx(I) THEN Xmx(I)=Real_data(J)
2181         IF Real_data(J)<Xmn(I) THEN Xmn(I)=Real_data(J)
2182         Mean=Mean+Real_data(J)
2183     NEXT J
2184     Mean=Mean/Num_points
2185     Dev=0
2186     FOR J=First_pnt TO Last_pnt
2187         Dev=(Real_data(J)-Mean)^2+Dev
2188     NEXT J
2189     Xsd(I)=((Dev/Num_points)^(.5))
2190     Xav(I)=Mean
2191 Nexti: !

```

```

2192 NEXT Plot
2193 DISP ""
2194 GOSUB Print_stats
2195 DEALLOCATE Xsd(*),Xav(*),Xmx(*),Xmn(*) !!!,Lunt$(*)
2196 RETURN
2197 !
2198 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2199 !
2200 Print_stats:
2201 GRAPHICS OFF
2202 ALPHA ON
2203 Dat$=DATE$(Digdate)
2204 !PRINT USING "0"
2205 PRINT
2206 PRINT "Date Digitized: ";Dat$
2207 PRINT "Digitizing Rate: ";Hz;" Hz/Channel"
2208 PRINT "Filter Frequency: ";Filt;" Hz"
2209 PRINT
2210 PRINT TAB(35);"STATISTICS"
2211 PRINT
2212 Stline1: IMAGE 18X,18A,3D.DD,4A,3D.DD,8A
2213 Stline2: IMAGE 22A,15A,15A,15A,13A
2214 Stline3: IMAGE 20A,6D.DD,6X,6D.DD,9X,6D.DD,6X,6D.DD
2215 PRINT USING Stline1;"For Interval from",First_pnt/Hz," to",Last_pnt/Hz," S
econds"
2216 PRINT
2217 PRINT USING Stline2;"CHANNEL","MINIMUM","MAXIMUM","MEAN VALUE","STANDARD D
EV"
2218 PRINT
2219 FOR J=1 TO Nplot
2220 IF Pgstat$(Page,J)=""YES" THEN
2221 PRINT USING Stline3;Pgsignal$(Page,J),Xmn(J),Xmx(J),Xav(J),Xsd(J)
2222 END IF
2223 NEXT J
2224 RETURN
2225 !
2226 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2227 !
2228 Set_intervals:
2229 VIEWPORT 12,102,0,100
2230 WINDOW 1,Num_points,0,100
2231 Cur=1
2232 GOSUB Clearkeys
2233 Int_keys:
2234 ON KEY 5 LABEL " ZEROINT",11 GOSUB Fix_zero_inter
2235 ON KEY 6 LABEL " DATAINT",11 GOSUB Fix_data_inter
2236 ON KEY 7 LABEL " PWR2INT",11 GOSUB Fix_pwr2_inter
2237 ON KEY 9 LABEL " EXIT",11 GOTO Set_interv_exit
2238 GOTO Int_keys
2239 !
2240 Set_interv_exit:
2241 Intervals_set=1

```

```

2242 GOSUB Store_run_file
2243 RETURN
2244 !
2245 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2246 !
2247 Fix_zero_inter: !
2248 GOSUB Clearkeys
2249 Cur=1
2250 Resp2_ret: !
2251 PEN 0
2252 MOVE Cur,100-Topm+4
2253 DRAW Cur,Bot
2254 ON KNOB .1,15 GOTO Knb_resp2
2255 ON KEY 5 LABEL " ZEROLOW",12 GOSUB Set_zero_low
2256 ON KEY 6 LABEL " ZEROHIGH",12 GOSUB Set_zero_high
2257 ON KEY 7 LABEL " CALCZEROS",12 GOSUB Calc_new_zero
2258 ON KEY 9 LABEL " EXIT",12 GOTO Set_zero_exit
2259 GOTO 2259
2260 !
2261 Knb_resp2: !
2262 FOR I=1 TO 3
2263     PEN 0
2264     MOVE Cur,100-Topm+4
2265     DRAW Cur,Bot
2266 NEXT I
2267 GOSUB Pulses
2268 GOTO Resp2_ret
2269 !
2270 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2271 !
2272 Set_zero_exit: !
2273 FOR I=1 TO 3
2274     PEN 0
2275     MOVE Cur,100-Topm+4
2276     DRAW Cur,Bot
2277 NEXT I
2278 GOSUB Clearkeys
2279 PEN 1
2280 OFF KNOB
2281 RETURN
2282 !
2283 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2284 !
2285 Set_zero_low: !
2286 GOSUB Get_cur
2287 Zerolow=INT(Cur)
2288 RETURN
2289 !
2290 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2291 !
2292 Set_zero_high: !
2293 GOSUB Get_cur

```



```

2294 Zerohigh=INT(Cur)
2295 RETURN
2296 !
2297 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2298 !
2299 Calc_new_zero: !
2300 GRAPHICS OFF
2301 FOR Channel=Start_chan TO Stop_chan
2302     DISP "CALCULATING ZEROLEVEL FOR CHANNEL: ";Channel
2303     F1$=Nm$&Cid$(Channel)&D1$
2304     ASSIGN @In TO F1$
2305     ALLOCATE INTEGER X_in(Npts)
2306     ON END @In GOTO 2309
2307     ENTER @In;X_in(*)
2308     OFF END @In
2309     Zer=0
2310     FOR I=ZeroLow TO Zerohigh
2311         Zer=X_in(I)+Zer
2312     NEXT I
2313     Xzer(Channel)=Zer/(Zerohigh-ZeroLow+1)
2314     ASSIGN @In TO *
2315     DEALLOCATE X_in(*)
2316 NEXT Channel
2317 ALPHA OFF
2318 GRAPHICS ON
2319 RETURN
2320 !
2321 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2322 !
2323 Fix_data_inter: !
2324 OFF KEY
2325 GOSUB Clearkeys
2326 Respl_ret: !
2327 PEN 0
2328 MOVE Cur,100-Topm+4
2329 DRAW Cur,Bot
2330 ON KNOB .1,15 GOTO Knob_resp
2331 ON KEY 5 LABEL "    DATALOW",12 GOSUB Set_dataLow
2332 ON KEY 6 LABEL "    DATAHIGH",12 GOSUB Set_datahigh
2333 ON KEY 9 LABEL "    EXIT",12 GOTO Fix_interv_exit
2334 GOTO 2334
2335 !
2336 Knob_resp: !
2337 FOR I=1 TO 3             ! LOOP 3 TIMES TO COMPLEMENT
2338     PEN 0                 ! TO ORIGINAL
2339     MOVE Cur,100-Topm+4
2340     DRAW Cur,Bot
2341 NEXT I
2342 GOSUB Pulses
2343 GOTO Respl_ret
2344 !
2345 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

```

```

2346 !
2347 Fix_interv_exit: !
2348 FOR I=1 TO 3
2349     MOVE Cur,100-Topm+4
2350     DRAW Cur,Bot
2351 NEXT I
2352 PEN 1
2353 GOSUB Clearkeys
2354 OFF KNOB
2355 RETURN
2356 !
2357 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2358 !
2359 Set_datalow: !
2360 Lowint=Lowint+1
2361 GOSUB Get_cur
2362 Datalow(Lowint)=INT(Cur)
2363 RETURN
2364 !
2365 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2366 !
2367 Set_datahigh: !
2368 Highint=Highint+1
2369 GOSUB Get_cur
2370 Datahigh(Highint)=INT(Cur)
2371 RETURN
2372 !
2373 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2374 !
2375 Fix_pwr2_inter: !
2376 GOSUB Clearkeys
2377 Cur=1
2378 Cur2=128
2379 Cur_pwr2=128
2380 Resp3_ret: !
2381 PEN 0
2382 MOVE Cur,100-Topm+4
2383 DRAW Cur,Bot
2384 MOVE Cur2,100-Topm+4
2385 DRAW Cur2,Bot
2386 ON KNOB .1,15 GOTO Resp3_knob
2387 ON KEY 5 LABEL "    PWR2INC",12 GOSUB Inc_pwr2
2388 ON KEY 6 LABEL "    PWR2DEC",12 GOSUB Dec_pwr2
2389 ON KEY 7 LABEL "    FIXPWR2",12 GOSUB Fix_pwr2
2390 ON KEY 9 LABEL "    EXIT",12 GOTO Pwr2_inter_exit
2391 GOTO 2391
2392 !
2393 Resp3_knob: !
2394 PEN 0
2395 FOR I=1 TO 3
2396     MOVE Cur,100-Topm+4
2397     DRAW Cur,Bot

```

```

2398     MOVE Cur2,100-Topm+4
2399     DRAW Cur2,Bot
2400 NEXT I
2401 GOSUB Pulses2
2402 GOTO Resp3_ret
2403 !
2404 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2405 !
2406 Pwr2_inter_exit:
2407 PEN 0
2408 FOR I=1 TO 3
2409     MOVE Cur,100-Topm+4
2410     DRAW Cur,Bot
2411     MOVE Cur2,100-Topm+4
2412     DRAW Cur2,Bot
2413 NEXT I
2414 GOSUB Clearkeys
2415 PEN 1
2416 OFF KNOB
2417 RETURN
2418 !
2419 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2420 !
2421 Inc_pwr2:
2422 IF Cur2+Cur_pwr2>Num_points THEN
2423     GRAPHICS OFF
2424     ALPHA ON
2425     DISP "INCREMENT TOO LARGE"
2426     WAIT 1
2427     DISP ""
2428     ALPHA OFF
2429     GRAPHICS ON
2430 ELSE
2431     PEN 0
2432     FOR I=1 TO 3
2433         MOVE Cur2,100-Topm+4
2434         DRAW Cur2,Bot
2435     NEXT I
2436     Cur2=Cur2+Cur_pwr2
2437     Cur_pwr2=Cur_pwr2*2
2438     PEN 0
2439     MOVE Cur2,100-Topm+4
2440     DRAW Cur2,Bot
2441 END IF
2442 RETURN
2443 !
2444 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2445 !
2446 Dec_pwr2:
2447 IF Cur2-Cur_pwr2/2<Cur THEN
2448     GRAPHICS OFF
2449     ALPHA ON

```

```

2450     DISP "DECREMENT TOO LARGE"
2451     WAIT 1
2452     DISP ""
2453     ALPHA OFF
2454     GRAPHICS ON
2455 ELSE
2456     PEN 0
2457     FOR I=1 TO 3
2458         MOVE Cur2,100-Topm+4
2459         DRAW Cur2,Bot
2460     NEXT I
2461     PEN 0
2462     Cur2=Cur2-Cur_pwr2/2
2463     Cur_pwr2=Cur_pwr2/2
2464     MOVE Cur2,100-Topm+4
2465     DRAW Cur2,Bot
2466 END IF
2467 RETURN
2468 !
2469 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2470 !
2471 Fix_pwr2:
2472 Power2low=INT(Cur)
2473 Power2high=INT(Cur2)
2474 PEN 1
2475 MOVE Cur,100-Topm
2476 DRAW Cur,100
2477 MOVE Cur2,100-Topm
2478 DRAW Cur2,100
2479 RETURN
2480 !
2481 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2482 !
2483 Pulses2:
2484 Knob_count=KNOBX/120*Num_points/5
2485 Cur=Cur+Knob_count
2486 Cur2=Cur2+Knob_count
2487 RETURN
2488 !
2489 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2490 !
2491 Pulses:
2492 Cur=Cur+KNOBX/120*Num_points/5
2493 IF Cur<1 THEN Cur=Num_points
2494 IF Cur>Num_points THEN Cur=1
2495 RETURN
2496 !
2497 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2498 !
2499 Get_cur:
2500 PEN 1
2501 MOVE Cur,100-Topm

```

```

2502 DRAW Cur,100
2503 RETURN
2504 !
2505 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2506 Store_run_file: !
2507 Storeflag=1
2508 CALL Runread(Storeflag)
2509 RETURN
2510 !
2511 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2512 Graphout: !
2513 DEALLOCATE Data(*),Area(*),Real_data(*)
2514 GRAPHICS OFF
2515 ALPHA ON
2516 SUBEND
2517 !
2518 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2519 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2520 SUB Runread(Storeflag)
2521 OPTION BASE 1
2522 COM /A110/ Job$,Nm$,Tst$,Run$
2523 COM /A111/ D0$,D1$,W0$,W1$,D2$
2524 COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Postrun
2525 COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
2526 COM /A114/ REAL Filt,Ttot,Digdate,Ztime
2527 COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
2528 !
2529 COM /Gph2/ INTEGER Zerolow,Zerohigh,Power2low,Power2high
2530 COM /Gph3/ INTEGER Pages,Datalow(*),Datahigh(*)
2531 COM /Gph4/ REAL Xzer(*),Scalemin(*),Scalemax(*)
2532 !
2533 DIM Dum$(4)
2536 Postrun=0
2539 !ON ERROR GOTO Out
2540 ASSIGN @Info TO Nm$&D0$
2542 SELECT Storeflag
2543     CASE 0
2544         DISP "READING PARAMETER FILE: ",Nm$
2545         ENTER @Info,1;Dum$,Start_chan,Stop_chan,HZ,Filt,Npts,Digdate,Ttot,Zti
me,Nchan,Zerolow,Zerohigh,Datalow(*),Datahigh(*),Power2low,Power2high
2546     CASE 1
2547         DISP "WRITING PARAMETER FILE: ";Nm$
2548         OUTPUT @Info,1;Dum$,Start_chan,Stop_chan,HZ,Filt,Npts,Digdate,Ttot,Zt
ime,Nchan,Zerolow,Zerohigh,Datalow(*),Datahigh(*),Power2low,Power2high
2549     END SELECT
2550 Postrun=1
2551 Chan=Start_chan
2553 FOR I=2 TO Nchan+1
2554     SELECT Storeflag
2555         CASE 0
2556             ENTER @Info,I;Cid$(Chan),Unit$(Chan),Conv(Chan),Xzer(Chan)
2557         CASE 1

```

```

2558             OUTPUT @Info,I;Cid$(Chan),Unit$(Chan),Conv(Chan),Xzer(Chan)
2559     END SELECT
2560     Chan=Chan+1
2561     PRINT "I IS ",I,"CHAN IS",Chan
2562 NEXT I
2563 !
2564 Out: !
2568 OFF ERROR
2569 DISP ""
2570 SUBEND
2571 !
2572 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2573 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2574 SUB Separate
2575     GOSUB Init                                ! Subprogram separates large
2576     GOSUB Select_drive                        ! all channel file into
2577     GOSUB Read_job_file                       ! individual files for each
2578     GOSUB Read_data_file                     ! channel
2579     GOSUB Store_chn_files
2580     GOSUB Store_job_file
2581     GOSUB Purge_allfile
2582     GOTO Sub_exit
2583 !
2584 Init: !
2585     OPTION BASE 1
2586     COM /A110/ Job$,Nm$,Tst$,Run$
2587     COM /A111/ D0$,D1$,W0$,W1$,D2$
2588     COM /A112/ INTEGER Pr,Crt,Gpio,Firstscan,Postrun
2589     COM /A113/ INTEGER Hz,Npts,Start_chan,Stop_chan,Nchan
2590     COM /A114/ REAL Filt,Ttot,Digdate,Ztime
2591     COM /A115/ REAL Conv(*),Unit$(*),Cid$(*)
2592 !
2593     COM /Gph0/ Title$,Plotlist$(*),Pglabel$(*)
2594     COM /Gph1/ Pgstat$(*),Pgsignal$(*)
2595     COM /Gph2/ INTEGER Zerolow,Zerohigh,Power2low,Power2high
2596     COM /Gph3/ INTEGER Pages,Datalow$(*),Datahigh$(*)
2597     COM /Gph4/ REAL Xzer$(*),Scalemin$(*),Scalemax$(*)
2598 !
2599     INTEGER I,J,Chan,Rec,Adress
2600     DIM Out_drive$(10)
2601     PRINT USING "@ "
2602     RETURN
2603 !
2604 Select_drive: !
2605     DISP "SELECT DRIVE FOR CHANNEL FILES OUTPUT"
2606     ON KEY 5 LABEL " HARD DISC" GOTO Hard
2607     ON KEY 6 LABEL " FLOPPY IN HD" GOTO Floppy3
2608     ON KEY 8 LABEL " LEFT FLOPPY" GOTO Floppy1
2609     ON KEY 9 LABEL " RIGHT FLOPPY" GOTO Floppy2
2610     Wait_for_key: !
2611     GOTO Wait_for_key
2612 Hard: !

```



```

2613 Out_drive$=W0$
2614 GOTO Select_exit
2615 Floppy1: !
2616 Out_drive$=D0$
2617 GOTO Select_exit
2618 Floppy2: !
2619 Out_drive$=D1$
2620 GOTO Select_exit
2621 Floppy3: !
2622 Out_drive$=D2$
2623 GOTO Select_exit
2624 Select_exit: !
2625 RETURN
2626 !
2627 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2628 !
2629 Read_job_file: !
2630 Storeflag=0
2631 CALL Runread(Storeflag)
2632 PRINT "NPTS= ";Npts;" HZ= ";Hz;" ZTIME= ";Ztime;" NCHAN= ";Nchan
2633 RETURN
2634 !
2635 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2636 !
2637 Read_data_file: !
2638 DISP "READING ALL DATA FILE: ",Nm$&"ALL"
2639 ASSIGN @Indata TO Nm$&"ALL"&W0$
2640 ON END @Indata GOTO 2643
2641 ALLOCATE INTEGER Alldata(Npts,Nchan)
2642 ENTER @Indata;Alldata(*)
2643 OFF END @Indata
2644 ASSIGN @Indata TO *
2645 RETURN
2646 !
2647 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2648 !
2649 Store_chn_files: !
2650 Inchan=Nchan
2651 !INPUT "CHAN?",Chan
2652 !Inchan=Nchan-(32-Chan)
2653 FOR Chan=Stop_chan TO Start_chan STEP -1
2654     DISP "PROCESSING CHANNEL ";Chan
2655     ALLOCATE INTEGER Outdata(Npts)
2656     FOR I=1 TO Npts
2657         Outdata(I)=Alldata(I,Inchan)
2658     NEXT I
2659     GOSUB Find_zeros
2660     F1$=Nm$&C10$(Chan)&Out_drive$
2661     CREATE BOAT F1$,1,Npts*2
2662     ASSIGN @Out TO F1$
2663     OUTPUT @Out;Outdata(*)
2664     ASSIGN @Out TO *

```



```

2717 INPUT "Input the date in the form DD MMM YYYY",Ans$
2718 IF Ans$<>"" THEN SET TIMEDATE DATE(Ans$)
2719 Ans$=""
2720 !
2721 INPUT "Input the time in the form HH:MM:SS",Ans$
2722 IF Ans$<>"" THEN SET TIME TIME(Ans$)
2723 !
2724 OFF ERROR
2725 PRINT USING "0"
2726 FOR I=1 TO 100
2727     DISP DATE$(TIMEDATE);"      ";TIME$(TIMEDATE)
2728 NEXT I
2729 DISP ""
2730 GOTO Sub_exit
2731 !
2732 Err3: !
2733 DISP "INCORRECT FORMAT ... TRY AGAIN"
2734 WAIT 3
2735 GOTO Top
2736 !
2737 Sub_exit: !
2738 SUBEND
2739 !
2740 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
2741 Xyplot: SUB Xyplot(X(*),Y(*),T1$,T2$,Tx$,Ty$,Xmin,Xmax,Xtick,Ymin,Ymax,Ytic
k,Ynull,INTEGER I0,I1,Repeat,Plottype,Opt1,Opt2,Hard)
2742 !
2743 ! X(*)           : X DATA POINTS
2744 ! Y(*)           : Y DATA POINTS
2745 ! T1,T2$        : TITLES AT TOP OF PAGE
2746 ! TX,TY$        : TITLES FOR AXES
2747 ! XMIN,XMAX,XTICK : X AXIS SCALING, AUTO-SCALED IF XMIN=XMAX
2748 ! YMIN,YMAX,YTICK : Y AXIS SCALING, AUTO-SCALED IF XMIN=XMAX
2749 ! I0,I1         : LOWER,UPPER LIMITS OF X,Y,ARRAYS
2750 ! Repeat        : IF 0, INITIALIZE TO START NEW PLOT
                    : IF >0, VALUES BEING PLOTTED ON TOP OF OLD DATA
2751 !
2752 ! Plottype       : 0: LIN-LIN; 1: LOG-LIN; 2: LIN-LOG; 3: LOG-LOG
2753 !                : 4: EXTREME 1; 5: EXTREME 2; 6: NORMAL; ALL WRT
2754 !                : Y VS X
2755 ! Opt1           : 0: PLOT DOTS; 1: JOIN POINTS WITH CONTINUOUS LINE
2756 !                : 2: HISTOGRAM; 3: ?           ; 4: CROSSES; 5: TRIANGLES
2757 !                : 6: X'S; 7: BOXES
2758 ! Opt2           : 0: FULL LINES GRIDS; 1: SHORT LINE GRIDS
2759 ! Hard           : 0: NO HARD COPY; 1: PLOTTER; 2: THINKJET DUMP
2760 !                : 3: EPSON; 4: EPSON ROTATED 11: THINKJET DUMP
2761 ! YNULL         : WILL NOT DRAW LINES OF ZERO VALUES
2762 GOSUB Init
2763 IF NOT Repeat THEN GOSUB Scaleandlabel
2764 GRAPHICS ON
2765 ALPHA OFF
2766 GOSUB Convertvalues
2767 GOSUB Plotvalues

```

```

2768 GOSUB Hardcopy
2769 DEALLOCATE Xc(*),Yc(*)
2770 SUBEXIT
2771 ! .....
2772 Init: !
2773 INTEGER I,J,Erflag,Dirflag,Labeltype
2774 DIM T1$(40)
2775 X1=20 ! GDU UNITS
2776 Xr=123
2777 Y1=15
2778 Yu=85
2779 RETURN
2780 ! .....
2781 Hardcopy: !
2782 SELECT Hard ! BASED ON TYPE OF HARDCOPY DESIRED, IF ANY
2783 CASE -1,0 ! NO HARDCOPY
2784 IF Hard=-1 THEN PAUSE
2785 RETURN ! LEAVE PLOT ON SCREEN
2786 CASE 1,11 ! PLOTTER
2787 IF Hard=1 THEN ! ASK IF HARDCOPY DESIRED
2788 GOSUB Permission
2789 ELSE ! ASSUME IT IS
2790 H$="Y"
2791 END IF
2792 IF H$="Y" THEN
2793 PLOTTER IS 705,"HPGL"
2794 IF NOT Repeat THEN
2795 GOSUB Labelaxes
2796 WINDOW Xmin,Xmax,Ymin,Ymax
2797 GOSUB Labelplot
2798 END IF
2799 GOSUB Plotvalues
2800 PENUP
2801 PLOTTER IS 3,"INTERNAL"
2802 END IF
2803 CASE 2,21 ! THINKJET-NEEDS WORK
2804 IF Hard=2 THEN
2805 GOSUB Permission
2806 ELSE
2807 H$="Y"
2808 END IF
2809 IF H$="Y" THEN ! DUMP IF WANT HARDCOPY
2810 DUMP DEVICE IS 701
2811 DUMP GRAPHICS
2812 END IF
2813 CASE 3,31 ! EPSON- NEEDS WORK
2814 IF Hard=3 THEN
2815 GOSUB Permission
2816 ELSE
2817 H$="Y"
2818 END IF
2819 IF H$="Y" THEN

```

```

2820     CALL Gdump
2821     END IF
2822     CASE 4,41      ! EPSON ROTATED 90 DGRESS- NEEDS WORK
2823     IF Hard=4 THEN
2824         GOSUB Permission
2825     ELSE
2826         HS="Y"
2827     END IF
2828     IF HS="Y" THEN
2829         CALL Gdump90
2830     END IF
2831     END SELECT
2832     GRAPHICS OFF
2833     ALPHA ON
2834     SUBEXIT
2835     ! .....
2836     Scaleandlabel:      !
2837     GINIT                ! ON FIRST PASS ONLY
2838     IF Xmin=Xmax THEN    ! SCALES NOT GIVEN SO AUTO-SCALE
2839         SELECT Plotttype
2840             CASE 0,1      ! LINEAR X AXIS
2841                 Labeltype=0
2842                 CALL Nicescale(X(*),Xmin,Xmax,Xtick,I0,I1,Labeltype,Erflag)
2843             CASE 2,3
2844                 Labeltype=1      ! LOG AXIS
2845                 CALL Nicescale(X(*),Xmin,Xmax,Xtick,I0,I1,Labeltype,Erflag)
2846             CASE 4,5      ! EXTREME VALUE PLOTS
2847                 Xmin=-LOG(-LOG(.01))
2848                 Xmax=-LOG(-LOG(.9999))
2849             CASE 6
2850                 CALL Findz(.5,0,Xmin,Erflag) ! Xmin,Xmax ARE Z VALUES CORRES-
2851                 CALL Findz(.999,3,Xmax,Erflag) ! PONDING TO PROB'S OF .5,.999
2852         END SELECT
2853     ELSE
2854         IF Xtick=0 AND Plotttype<>4 AND Plotttype<>5 THEN ! CHECK FOR POSSIBLE
2855             GRAPHICS OFF      ! ERROR DUE TO Xtick
2856             ALPHA ON
2857             PRINT "XTICK=0 IN XYPLOT ROUTINE"
2858             PAUSE
2859         END IF
2860     END IF
2861     IF Ymin=Ymax THEN    ! SCALES NOT GIVEN SO AUTO-SCALE
2862         SELECT Plotttype
2863             CASE 0,2,4,6    ! LINEAR Y AXIS
2864                 Labeltype=0
2865                 CALL Nicescale(Y(*),Ymin,Ymax,Ytick,I0,I1,Labeltype,Erflag)
2866             CASE 1,3
2867                 Labeltype=1      ! LOG AXIS
2868                 CALL Nicescale(Y(*),Ymin,Ymax,Ytick,I0,I1,Labeltype,Erflag)
2869             CASE 5          ! EXTREME VALUE TYPE 2 ASSUMES DATA IN
2870                 Ymax=INT(LGT(Y(I1)))+1 ! ASCENDING ORDER
2871                 Ymin=INT(LGT(Y(I0)))

```

```

2872         Ytick=1
2873     END SELECT
2874 ELSE
2875     IF Ytick=0 THEN             ! CHECK FOR POSSIBLE ERROR DUE TO YTICK
2876         GRAPHICS OFF
2877         ALPHA ON
2878         PRINT "YTICK=0 IN XYPLOT ROUTINE"
2879         PAUSE
2880     END IF
2881 END IF
2882 VIEWPORT X1,Xr,Y1,Yu
2883 GRAPHICS ON
2884 ALPHA OFF
2885 GOSUB Labelaxes                ! ONLY LABEL ON FIRST PASS
2886 WINDOW Xmin,Xmax,Ymin,Ymax
2887 GOSUB Labelplot
2888 RETURN
2889 ! .....
2890 Labelaxes:                    !
2891     Dirflag=0                  ! LABEL Y AXIS
2892     WINDOW X1,Xr,Ymin,Ymax
2893     SELECT Plotttype
2894     CASE 0,2,4,6
2895         CALL Linlabel(Ty$,X1,Xr,Y1,Yu,Ymin,Ymax,Ytick,Dirflag,Opt2)
2896     CASE 1,3,5
2897         CALL Loglabel(Ty$,X1,Xr,Y1,Yu,Ymin,Ymax,Stick,Dirflag,Opt2)
2898     END SELECT
2899     Dirflag=1                  ! LABEL X AXIS
2900     WINDOW Xmin,Xmax,Y1,Yu
2901     SELECT Plotttype
2902     CASE 0,1
2903         CALL Linlabel(Tx$,X1,Xr,Y1,Yu,Xmin,Xmax,Xtick,Dirflag,Opt2)
2904     CASE 2,3
2905         CALL Loglabel(Tx$,X1,Xr,Y1,Yu,Xmin,Xmax,Xtick,Dirflag,Opt2)
2906     CASE 4,5
2907         CALL Extremelabel(X1,Xr,Y1,Yu,Xmin,Xmax,Dirflag,Opt2)
2908     CASE 6
2909         CALL Normlabel(X1,Xr,Y1,Yu,Dirflag,Opt2)
2910     END SELECT
2911     WINDOW X1,Xr,Y1,Yu
2912     FRAME
2913     RETURN
2914 ! .....
2915 Labelplot:                    !
2916     CSIZE 4
2917     CLIP OFF
2918     MOVE (Xmin+Xmax)/2,Ymax+.11*(Ymax-Ymin)
2919     LORG 4
2920     LABEL T1$
2921     LABEL T2$
2922     RETURN
2923 ! .....

```



```

2924 Convertvalues:          ! CONVERT VALUES FOR PLOTTING ON LOG SCALES IF
2925 ALLOCATE Xc(I1-I0+1),Yc(I1-I0+1) ! NECESSARY. IGNORE BOGUS POINTS
2926 J=0
2927 SELECT Plottype
2928     CASE 0,4              ! LIN-LIN OR EXTREME VALUE TYPE 1
2929         FOR I=I0 TO I1
2930             J=J+1
2931             Xc(J)=X(I)
2932             Yc(J)=Y(I)
2933         NEXT I
2934     CASE 1,5              ! LOG-LIN PLOT OR EXTREME VALUE TYPE 2
2935         FOR I=I0 TO I1
2936             IF Y(I)>0 THEN
2937                 J=J+1
2938                 Xc(J)=X(I)
2939                 Yc(J)=LGT(Y(I))
2940             END IF
2941         NEXT I
2942     CASE 2
2943         FOR I=I0 TO I1
2944             IF X(I)>0 THEN
2945                 J=J+1
2946                 Xc(J)=LGT(X(I))
2947                 Yc(J)=Y(I)
2948             END IF
2949         NEXT I
2950     CASE 3                ! LOG-LOG PLOT
2951         FOR I=I0 TO I1
2952             IF X(I)>0 AND Y(I)>0 THEN
2953                 J=J+1
2954                 Xc(J)=LGT(X(I))
2955                 Yc(J)=LGT(Y(I))
2956             END IF
2957         NEXT I
2958     CASE 6
2959         FOR I=I0 TO I1
2960             J=J+1
2961             CALL Findz(X(I),.6,Xc(J),Erflag)
2962             Yc(J)=Y(I)
2963         NEXT I
2964     CASE ELSE
2965         GRAPHICS OFF
2966         ALPHA ON
2967         PRINT "ERROR IN PLOTTYPE VALUE IN XYPLOT ROUTINE"
2968         PAUSE
2969     END SELECT
2970 RETURN
2971 ! .....
2972 Plotvalues:              !
2973 CLIP ON
2974 SELECT Opt1
2975     CASE 0                ! PLOT DOTS

```

```

2976     FOR I=1 TO J
2977         MOVE Xc(I),Yc(I)
2978         DRAW Xc(I),Yc(I)
2979     NEXT I
2980 CASE 1                                ! JOIN NON NULL CONSECUTIVE POINTS WITH
2981 PRINT Xc(1),Yc(1)                    ! CONTINUOUS LINE
2982     MOVE Xc(1),Yc(1)                  ! PLOTS DOTS FOR SINGLE NON NULL POINTS
2983     FOR I=2 TO J
2984         IF Yc(I)<>Ynull AND Yc(I-1)<>Ynull THEN
2985             DRAW Xc(I),Yc(I)
2986         ELSE
2987             MOVE Xc(I),Yc(I)
2988             IF Yc(I)<>Ynull THEN DRAW Xc(I),Yc(I)
2989         END IF
2990     NEXT I
2991 CASE 2                                ! HISTOGRAM
2992     MOVE Xc(1),Yc(1)
2993     FOR I=1 TO J-1
2994         DRAW Xc(I+1),Yc(I)
2995         DRAW Xc(I+1),Yc(I+1)
2996     NEXT I
2997     DRAW Xmax,Yc(J)
2998 CASE 3                                ! DIAMONDS
2999     Dx=(Xmax-Xmin)/(Xr-Xl)/2
3000     Dy=(Ymax-Ymin)/(Yu-Yl)/2
3001     FOR I=1 TO J
3002         MOVE Xc(I)-Dx,Yc(I)
3003         DRAW Xc(I),Yc(I)+Dy
3004         MOVE Xc(I)+Dx,Yc(I)
3005         DRAW Xc(I),Yc(I)+Dy
3006         DRAW Xc(I)-Dx,Yc(I)
3007     NEXT I
3008 CASE 4                                ! CROSSES
3009     Dx=(Xmax-Xmin)/(Xr-Xl)*.8
3010     Dy=(Ymax-Ymin)/(Yu-Yl)*.8
3011     FOR I=1 TO J
3012         MOVE Xc(I)-Dx,Yc(I)
3013         DRAW Xc(I)+Dx,Yc(I)
3014         MOVE Xc(I),Yc(I)-Dy
3015         DRAW Xc(I),Yc(I)+Dy
3016     NEXT I
3017 CASE 5                                ! TRIANGLES
3018     Dx=(Xmax-Xmin)/(Xr-Xl)*.8
3019     Dy=(Ymax-Ymin)/(Yu-Yl)*.57735
3020     Dd=(Ymax-Ymin)/(Yu-Yl)*1.7321-Dy
3021     FOR I=1 TO J
3022         MOVE Xc(I),Yc(I)+Dd
3023         DRAW Xc(I)+Dx,Yc(I)-Dy
3024         DRAW Xc(I)-Dx,Yc(I)-Dy
3025         DRAW Xc(I),Yc(I)+Dd
3026     NEXT I
3027 CASE 6                                ! X'S

```



```

3080 | Opt2          : 0: FULL GRID LINES; 1: SHORT TICK MARKS
3081 |
3082 GOSUB Drawlines
3083 GOSUB Label
3084 SUBEXIT
3085 | .....
3086 Drawlines:      |
3087 SELECT Dirflag
3088 CASE 0           | Y AXIS
3089     SELECT Opt2
3090     CASE 0       | FULL GRID LINES
3091       LINE TYPE 4,1
3092       FOR Ydist=Smin+Stick TO Smax-Stick/2 STEP Stick
3093         MOVE X1,Ydist
3094         DRAW Xr,Ydist
3095       NEXT Ydist
3096     CASE 1       | SHORT GRID LINES
3097       Length=.02*MIN(Xr-X1,Yu-Y1)
3098       Xend1=X1+Length
3099       Xend2=Xr-Length
3100       FOR Ydist=Smin+Stick TO Smax-Stick/2 STEP Stick
3101         MOVE X1,Ydist
3102         DRAW Xend1,Ydist
3103         MOVE Xend2,Ydist
3104         DRAW Xr,Ydist
3105       NEXT Ydist
3106     END SELECT
3107     IF 0>Smin AND 0<Smax THEN | DRAW 0 REFERENCE IF SOMEWHERE IN MIDDLE
3108       LINE TYPE 4,1           | HARDCOPY LOOKS POOR IF ON EDGE
3109       MOVE X1,0
3110       DRAW Xr,0
3111     END IF
3112 CASE 1           | DRAW VERTICAL LINES FOR X AXIS
3113     SELECT Opt2
3114     CASE 0       | FULL GRID LINES
3115       LINE TYPE 4,1
3116       FOR Xdist=Smin+Stick TO Smax-Stick/2 STEP Stick
3117         MOVE Xdist,Y1
3118         DRAW Xdist,Yu
3119       NEXT Xdist
3120     CASE 1       | SHORT GRID LINES
3121       Length=.02*MIN(Xr-X1,Yu-Y1)
3122       Yend1=Y1+Length
3123       Yend2=Yu-Length
3124       LINE TYPE 1
3125       FOR Xdist=Smin+Stick TO Smax-Stick/2 STEP Stick
3126         MOVE Xdist,Y1
3127         DRAW Xdist,Yend1
3128         MOVE Xdist,Yend2
3129         DRAW Xdist,Yu
3130       NEXT Xdist
3131     END SELECT

```

```

3132 END SELECT
3133 RETURN
3134 ! .....
3135 Label: !
3136 CLIP OFF
3137 CSIZE 3
3138 LINE TYPE 1
3139 SELECT Dirflag
3140 CASE 0 ! LABEL Y AXIS
3141 Xdist=X1-.01*(Xr-X1) ! JUST TO LEFT OF GRAPH
3142 LONG 8
3143 FOR Ydist=Smin TO Smax+Stick/2 STEP Stick
3144 MOVE Xdist,Ydist
3145 IF ABS(Ydist)<1.E-9 THEN
3146 LABEL 0
3147 ELSE
3148 LABEL Ydist
3149 END IF
3150 NEXT Ydist
3151 DEG
3152 LDIR 90 ! ROTATE LABEL
3153 LONG 4
3154 MOVE X1-.1*(Xr-X1),(Smin+Smax)/2 ! TO LEFT OF GRAPH FOR LABEL
3155 LABEL Txy$
3156 LDIR 0
3157 CASE 1 ! LABEL X AXIS
3158 Ydist=Y1-.01*(Yu-Y1) ! JUST BELOW GRAPH
3159 DEG
3160 LONG 6
3161 FOR Xdist=Smin TO Smax+Stick/2 STEP Stick ! LABEL ACROSS BOTTOM
3162 MOVE Xdist,Ydist
3163 LABEL Xdist
3164 NEXT Xdist
3165 LONG 6
3166 LDIR 0
3167 MOVE (Smin+Smax)/2,Y1-.15*(Yu-Y1) ! FURTHER BELOW FOR Title
3168 LABEL Txy$ ! BOTTOM CENTER
3169 END SELECT
3170 CLIP ON
3171 RETURN
3172 ! .....
3173 SUBEND
3174 ! ~~~~~
3175 ! ~~~~~
3176 ! ~~~~~
3177 SUB Nicescale(A(*),Smin,Smax,Stick,INTEGER I0,I1,Flag,Erflag)
3178 ! A(*) : ARRAY CONTAINING DATA TO BE SCALED
3179 ! Smin,Smax,Stick: SCALE PARAMETERS
3180 ! I0,I1 : INDICES OF A(*) DATA SEARCHED FOR SCALING
3181 ! Flag : 0: LINEAR SCALING; 1: SCALED FOR LOG AXIS
3182 ! Erflag: LOG SCALE FLAG. 2: BOTH MAX AND MIN VALUES<=0
3183 ! 1: MIN VALUE <=0; 0: BOTH OKAY

```

```

3184 ! R BROWN, JAN 1985
3185 GOSUB Findmaxandmin
3186 SELECT Flag
3187     CASE 0                                ! WANT LINEAR SCALING
3188         GOSUB Findnicetick
3189         GOSUB Scalemaxandmin
3190     CASE 1                                ! WANT POWERS OF 10 FOR LOG SCALING
3191         GOSUB Logscale
3192 END SELECT
3193 SUBEXIT
3194 ! .....
3195 Findmaxandmin:                            ! FIND MAX AND MIN VALUE OF DATA
3196     Amax=-9.E+99
3197     Amin=9.E+99
3198     INTEGER I
3199     FOR I=I0 TO I1                        ! FIND MAX AND MIN BETWEEN INDICES I0,I1
3200         IF A(I)>Amax THEN Amax=A(I)
3201         IF A(I)<Amin THEN Amin=A(I)
3202     NEXT I
3203     Range=Amax-Amin
3204     IF Range=0 THEN
3205         GRAPHICS OFF
3206         ALPHA ON
3207         PRINT "DATA IS ALL ONE VALUE IN NICESCALE ROUTINE"
3208         PAUSE
3209         SUBEXIT
3210     END IF
3211     RETURN
3212 ! .....
3213 Findnicetick:                             ! RETURNS A NICE NO FOR TICK SPACING
3214     Inc=10*(INT(LGT(Range))-2)           ! IF 100<=RANGE<1000 THEN Inc=1
3215     Inc:   Inc=Inc*10
3216     IF Range>6*Inc THEN Try12
3217         Stick=Inc                        ! TICKS OF ...,1,10,100,...
3218         RETURN
3219     Try12: IF Range>12*Inc THEN Try30
3220         Stick=2*Inc                      ! TICKS OF ...,2,20,200,...
3221         RETURN
3222     Try30: IF Range>30*Inc THEN Inc
3223         Stick=5*Inc                      ! TICKS OF ...,5,50,500,...
3224         RETURN
3225 ! .....
3226 Scalemaxandmin:                          ! FIND SCALE EVENLY DIVISIBLE BY STICK
3227     IF Amax>=0 THEN
3228         Smax=Amax DIV Stick*Stick+Stick
3229     ELSE
3230         Smax=Amax DIV Stick*Stick
3231     END IF
3232     IF Amin>=0 THEN
3233         Smin=Amin DIV Stick*Stick
3234     ELSE
3235         Smin=Amin DIV Stick*Stick-Stick

```



```

3236 END IF
3237 RETURN
3238 ! .....
3239 Logscale:                ! Smax IS POWER THAT 10 IS RAISED TO
3240 Erflag=0
3241 IF Amax>0 THEN
3242     Smax=INT(LGT(Amax))+1    ! SO 10^SMAX>LARGEST VALUE
3243 ELSE
3244     Erflag=2                ! BOTH MIN AND MAX <=0
3245     RETURN
3246 END IF
3247 IF Amin>0 THEN
3248     Smin=INT(LGT(Amin))      ! AND 10^SMIN<SMALLEST
3249 ELSE
3250     Erflag=1                ! ONLY MIN IS <=0
3251     Smin=Smax-4             ! ARBITRARY 4 DECADE SCALE
3252 END IF
3253 Stick=1
3254 RETURN
3255 SUBEND
3256 ! .....

3784 SUB Average(X(*),Xmin,Time(*),Init_time,Last_time,Avg,Dev,INTEGER No_pts,No
_realpts)
3785 J=0
3786 Avg=0
3787 FOR I=1 TO No_pts
3788     IF X(I)>Xmin AND Time(I)>Init_time AND Time(I)<Last_time THEN
3789         Avg=Avg+X(I)
3790         J=J+1
3791     END IF
3792 NEXT I
3793 No_realpts=J
3794 IF J>0 THEN Avg=Avg/J
3795 Dev=0
3796 FOR I=1 TO No_pts
3797     IF X(I)>Xmin AND Time(I)>Init_time AND Time(I)<Last_time THEN
3798         Dev=(X(I)-Avg)^2+Dev
3799     END IF
3800 NEXT I
3801 IF J>0 THEN Dev=SQR(Dev/J)
3802 SUBEND

```

A.2 HULL INTERPOLATION SUBROUTINE

This appendix contains Table A.1 which gives the offsets used by the hull interpolation subroutine and a listing of the subroutine. The subroutine when given the sum of the forces on a segment and the sum of the moments computes by an iterative routine, the x, y, z position of the force on the hull and from this the normal and friction forces, the hull angles at x, z, and the orientation of the friction force. The subroutine fits cubic splines to the given hull offsets to determine offsets and hull angles at any point on the segments.

TABLE A.1

HULL COORDINATES USED IN HULL INTERPOLATION SUB-ROUTINE

VERTICAL COORDINATES (Absolute measurement is from the 24.75' WL)									
		14'W.L.	16'W.L.	20'W.L.	22'W.L.	23'W.L.	24'W.L.	25'W.L.	
		0.164m	0.135m	0.072m	0.042m	0.027m	0.011	-0.004m	
OFFSETS m									
LONGITUDINAL COORDINATES	STATION	X m							
SEGMENT 3	7	0.879	.454	.461	.472	.476	.478	.480	.482
	8	1.319	.388	.403	.427	.436	.440	.444	.447
	8.5	1.539	.311	.334	.371	.386	.393	.399	.405
	9	1.759	.192	.228	.282	.304	.315	.325	.334
SEGMENT 2	9.25	1.869	.117	.157	.225	.252	.265	.276	.288
	9.5	1.979	.033	.076	.158	.191	.208	.223	.235
	9.75	2.088	-	-	.085	.126	.146	.162	.176
SEGMENT 3	10	2.198	-	-	.012	.061	.083	.102	.117
	10.23	2.298	-	-	-	.013	.027	.047	.062
	10.46	2.398	-	-	-	-	.00	.004	.007

```

3257 Lforce: SUB Lforce(Rt,Ht,Vt,C1,C2,C3,Seg_no,Xorigin,Fnormal,Ffriction,Mu,X,
Z,Alpha,Beta,Phi,Psi,Segflag)
3258 ! PERFORM WATERLINE OR STATION INTERPOLATION USING CUBIC SPLINES OR
3259 ! POLYNOMIALS
3260 ! R BROWN FOR 1566
3261 ! MODIFIED BY T ROOTS AUG 25 1986
3262 ! MODIFIED BY ANN GODON OCT 1 1986
3263     DEG
3264     GOSUB Init2
3265     GOSUB Polynomials           ! GET CUBIC COEFFICIENTS FOR STATION
3266     GOSUB Splines             ! GET SPLINE COEFF FOR W/L
3267     Xf(1)=(C2+Rt*.0267)/Vt
3268     Err(1)=100
3269 ! PRINT "FIRST X IS",Xf(1)+Xorigin
3270     K=0
3271     REPEAT
3272         K=K+1
3273         X=Xf(K)+Xorigin
3274         Flag=0
3275         Z=.133
3276         Zcase=1
3277         GOSUB Waterlines
3278         Yf(K,1)=Y
3279         Err(2)=(Ht*Z-Vt*Yf(K,1)-C1)
3280         J=1
3281         REPEAT
3282             J=J+1
3283             L=J+1
3284             Z=Zwl(J)
3285             Zcase=J
3286             GOSUB Waterlines

```

```

3287         Yf(K,J)=Y
3288         Err(L)=(Ht*Zw1(J)-Vt*Yf(K,J)-C1)
3289         PRINT "Z=",Zw1(J),"Y=",Yf(K,J),"ERRC1=",Err(L)
3290         IF Err(L-1)>0 AND Err(L)<0 THEN Flag=1
3291         IF Err(L-1)<0 AND Err(L)>0 THEN Flag=1
3292         IF ABS(Err(L))>ABS(Err(L-1)) THEN Flag=1
3293     UNTIL (J=5) OR (Flag=1)
3294     IF ABS(Err(L))<=.01 THEN      ! RESETS SUBSCRIPTS IF ERR AT
3295                                   ! AT TOP WATERLINE IS LESS THAN .01
3296         J=J+1
3297         L=L+1
3298     END IF
3299     Y=Yf(K,J-1)
3300     Z=Zw1(J-1)
3301     Err1=Err(L-1)
3302     IF ABS(Err1)>.01 THEN
3303         Z=Zw1(J-1)+(Zw1(J)-Zw1(J-1))*(-Err(L-1))/(Err(L)-Err(L-1))
3304         IF Z<0. THEN
3305             PRINT "Z IS ABOVE THE SEGMENT"
3306             Z=-.001 ! SET TO -.001 TO DISTINGISH FROM CASES WHERE Z
3307                       ! WAS FOUND TO BE 0
3308         END IF
3309         GOSUB Waterline_itp
3310         Err1=(Ht*Z-Vt*Y-C1)
3311         PRINT "INTERPOLATION: Z=",Z,"Y=",Y,"ERRC1=",Err1
3312     END IF
3313     IF Y<0 THEN Z=Zw1(J)+(Z-Zw1(J))*(-Yf(K,J))/(Y-Yf(K,J))
3314     Err1=(Ht*Z-Vt*Y-C1)
3315     Xf(K+1)=(C2+Rt*Z)/Vt
3316     Xdiff=ABS(Xf(K+1)-Xf(K))
3317     PRINT "      XDIFF",Xdiff
3318     PRINT "      NEW X",Xf(K+1)+Xorigin
3319     UNTIL (K=5) OR (Xdiff<=.001)
3320     Err2=(Vt*Xf(K+1)-Rt*Z-C2)/C2
3321     Err3=(Rt*Y-Ht*Xf(K+1)-C3)/C3
3322     X=Xf(K+1)+Xorigin
3323     GOSUB Check_err
3324     GOSUB Seg_limits
3325     GOSUB Waterline_itp
3326     GOSUB Station_itp
3327     GOSUB Normals
3328     GOSUB Friction_coeff
3329     GOSUB Friction_angle
3330     GOTO End
3331 ! .....
3332 Seg_limits:      ! CHECKS THAT X AND Z ARE ON THE SEGMENT
3333     Segflag=0
3334     SELECT Seg_no
3335     CASE 1
3336         IF X>2.4 THEN Segflag=1 !X=2.4
3337         IF X<2.03 THEN Segflag=1 !X=2.03
3338         IF Z>-.27*X+.682 THEN Z=-.27*X+.682

```

```

3339 CASE 2
3340 ! X=X-.018
3341 ! Z=Z+.011
3342 IF X>2.025 THEN Segflag=1 !X=2.025
3343 IF X<1.621 THEN Segflag=1 !X=1.621
3344 CASE 3
3345 IF X>1.621 THEN Segflag=1 !X=1.621
3346 IF X<.89 THEN Segflag=1 !X=.89
3347 END SELECT
3348 IF Z>.15 THEN Segflag=1 !Z=.15
3349 IF Z<0 THEN Segflag=1
3350 ! IF Y<0 THEN Segflag=1 ! FOR SEG 1 WHEN THE FORCE IS ON THE BOW
3351 RETURN
3352 ! .....
3353 Normals: ! FINDS NORMALS FOR ALPHA AND BETA
3354 Theta=ATN(1/(TAN(Beta)*COS(Alpha)))
3355 N1=SIN(Theta)*SIN(Alpha)
3356 N2=SIN(Theta)*COS(Alpha)
3357 N3=COS(Theta)
3358 Fnormal=N1*Rt+N2*Ht+N3*Vt
3359 RETURN
3360 ! .....
3361 Select_station: ! STRAIGHT LINE INTERPOLATION BETWEEN STATIONS TO FIND
3362 ! BETA AT Xitp
3363 I=0
3364 REPEAT
3365 I=I+1
3366 Xcase=I
3367 UNTIL (I=8) OR (X>Xw3(I) AND X<=Xw3(I+1))
3368 IF X<=Xw3(I) THEN Xcase=I
3369 RETURN
3370 ! .....
3371 Station_itp: ! DOES INTERPOLATIONS BETWEEN STATIONS
3372 GOSUB Select_station
3373 GOSUB Stations
3374 Betal=Mbeta
3375 Xl=Xstation
3376 ! PRINT Xl,Betal,Z
3377 Xcase=Xcase+1
3378 GOSUB Stations
3379 Betah=Mbeta
3380 Xh=Xstation
3381 ! PRINT Xh,Betah,Z
3382 ! PRINT "X VALUES FOUND DURING BETA INTERPOLATIONS",Xl,Xh
3383 Beta=Betal+(Betah-Betal)*(X-Xl)/(Xh-Xl)
3384 RETURN
3385 ! .....
3386 Stations: !
3387 ! STATION INTERPOLATIONS Y AND Mbeta ARE FOUND
3388 SELECT Xcase ! SELECT POLY COEFF BASED ON COLUMN
3389 CASE 1
3390 Xstation=.879

```



```

3391      Slope=(3*As1(4)*Z+2*As1(3))*Z+As1(2)
3392      CASE 2
3393      Xstation=1.319
3394      Slope=(3*As2(4)*Z+2*As2(3))*Z+As2(2)
3395      CASE 3
3396      Xstation=1.539
3397      Slope=(3*As3(4)*Z+2*As3(3))*Z+As3(2)
3398      CASE 4
3399      Xstation=1.759
3400      Slope=(3*As4(4)*Z+2*As4(3))*Z+As4(2)
3401      CASE 5
3402      Xstation=1.869
3403      Slope=(3*As5(4)*Z+2*As5(3))*Z+As5(2)
3404      CASE 6
3405      Xstation=1.979
3406      Slope=(3*As6(4)*Z+2*As6(3))*Z+As6(2)
3407      CASE 7
3408      Xstation=2.088
3409      Slope=(3*As7(4)*Z+2*As7(3))*Z+As7(2)
3410      CASE 8
3411      Xstation=2.198
3412      Slope=(3*As8(4)*Z+2*As8(3))*Z+As8(2)
3413      CASE 9
3414      Xstation=2.298
3415      Slope=(3*As9(4)*Z+2*As9(3))*Z+As9(2)
3416      END SELECT
3417      Slope=ABS(Slope)
3418      Mbeta=ATN(Slope)
3419      RETURN
3420      ! .....
3421      Sel_waterlines:      ! SELECTS THE WATER LINE FOR INTERPOLATION
3422      I=0
3423      REPEAT
3424      I=I+1
3425      Zcase=I
3426      UNTIL (I=4) OR (Z<=Zw1(I) AND Z>Zw1(I+1))
3427      IF Z>Zw1(I) THEN Zcase=I
3428      RETURN
3429      ! .....
3430      Waterline_itp:      ! PERFORMS A STRAIGHT LINE INTERPOLATION BETWEEN 2
3431      GOSUB Sel_waterlines
3432      GOSUB Waterlines
3433      Alpha=Malpha
3434      Zl=Zwater
3435      Yl=Y
3436      Zcase=Zcase+1
3437      GOSUB Waterlines
3438      Alphah=Malpha
3439      Zh=Zwater
3440      Yh=Y
3441      Alpha=Alpha+(Alphah-Alpha)*(Z-Zl)/(Zh-Zl)
3442      Y=Yl+(Yh-Yl)*(Z-Zl)/(Zh-Zl)

```

```

3443 RETURN
3444 ! .....
3445 Waterlines: !
3446 I=0
3447 SELECT Zcase ! SELECT SPLINE VALUES BASED ON COLUMN
3448 CASE 1
3449     Zwater=.133
3450     REPEAT ! FIND INTERVAL X IS WITHIN
3451         I=I+1
3452         UNTIL (I=5) OR (X>Xw1(I) AND X<Xw1(I+1))
3453         CALL Spline_coeff(Xw1(*),Yw1(*),Sw1(*),A,B,C,D,I)
3454         Dx=X-Xw1(I)
3455     CASE 2
3456         Zwater=.072
3457         REPEAT
3458             I=I+1
3459             UNTIL (I=7) OR (X>Xw2(I) AND X<Xw2(I+1))
3460             CALL Spline_coeff(Xw2(*),Yw2(*),Sw2(*),A,B,C,D,I)
3461             Dx=X-Xw2(I)
3462     CASE 3
3463         Zwater=.042
3464         REPEAT
3465             I=I+1
3466             UNTIL (I=8) OR (X>Xw3(I) AND X<Xw3(I+1))
3467             CALL Spline_coeff(Xw3(*),Yw3(*),Sw3(*),A,B,C,D,I)
3468             Dx=X-Xw3(I)
3469     CASE 4
3470         Zwater=.0257
3471         REPEAT
3472             I=I+1
3473             UNTIL (I=9) OR (X>Xw4(I) AND X<Xw4(I+1))
3474             CALL Spline_coeff(Xw4(*),Yw4(*),Sw4(*),A,B,C,D,I)
3475             Dx=X-Xw4(I)
3476     CASE 5
3477         Zwater=.0114
3478         REPEAT
3479             I=I+1
3480             UNTIL (I=9) OR (X>Xw5(I) AND X<Xw5(I+1))
3481             CALL Spline_coeff(Xw5(*),Yw5(*),Sw5(*),A,B,C,D,I)
3482             Dx=X-Xw5(I)
3483     END SELECT
3484     Y=((A*Dx+B)*Dx+C)*Dx+D ! GIVEN COEFF AND X POS IN INTERVAL
3485     Slope=(3*A*Dx+2*B)*Dx+C ! CALC Y AND SLOPE
3486     Malpha=ATN(ABS(Slope))
3487 RETURN
3488 ! .....
3489 Friction_coeff: ! SUBROUTINE FINDS THE FRICTION COEFFICIENT MU AND THE
3490 ! NORMAL COSINES OF THE FRICTION COMPONENT FROM EQN 4.12
3491 ! 4.13 AND 4.14 OF S66C
3492 Ftotal=SQR(Rt*Rt+Ht*Ht+Vt*Vt)
3493 Ffriction=SQR(Ftotal*Ftotal-Fnormal*Fnormal)
3494 Mu1=Rt/Fnormal-N1

```

```

3495 Mu2=Ht/Fnormal-N2
3496 Mu3=Vt/Fnormal-N3
3497 Mu=SQRT(Mu1*Mu1+Mu2*Mu2+Mu3*Mu3)
3498 E1=Mu1/Mu
3499 E2=-Mu2/Mu
3500 E3=-Mu3/Mu
3501 RETURN
3502 ! .....
3503 Friction_angle: ! CALCULATES THE HULL FRICTION ANGLE RELATIVE TO
3504 ! THE HORIZONTAL ON THE HULL PLANE.
3505 Vm=-E3/SIN(Theta)
3506 Lm=-E3*TAN(Alpha)/TAN(Theta)+E1/COS(Alpha)
3507 Phi=ASN(Vm)
3508 IF Lm<0 THEN
3509     IF Vm>0 THEN Phi=180-Phi
3510     IF Vm<0 THEN Phi=-180-Phi
3511 END IF
3512 Psi=ACS(E1)
3513 IF E3>0 THEN Psi=-ACS(E1)
3514 PAUSE
3515 RETURN
3516 ! .....
3517 Check_err: ! PRINTS ERROR MESSAGES IF ERR1 OR ERR3 EXCEED LIMITS
3518 PRINT
3519     IF ABS(Err1)>.05 THEN PRINT "ROUTINE DID NOT FIND Z"
3520     IF ABS(Err3)>.500 THEN PRINT "ROUTINE MAY NOT HAVE FOUND X OR Z "
3521 RETURN
3522 ! .....
3523 Init2: !
3524 OPTION BASE 1
3525 INTEGER I,J,K,L,Iend,N,In
3526 ! STATION INTERPOLATION VALUES
3527 DIM Xw1(6),Xw2(8),Xw3(9),Xw4(10),Xw5(10)
3528 DIM Yw1(6),Yw2(8),Yw3(9),Yw4(10),Yw5(10)
3529 DIM Sw1(50),Sw2(50),Sw3(50),Sw4(50),Sw5(50)
3530 !
3531 DIM Zs1(4),Zs2(4),Zs3(4)
3532 DIM Ys1(4),Ys2(4),Ys3(4),Ys4(4),Ys5(4),Ys6(4),Ys7(4),Ys8(4),Ys9(4)
3533 DIM As1(4),As2(4),As3(4),As4(4),As5(4),As6(4),As7(4),As8(4),As9(4)
3534 DIM Xf(10),Yf(10,10),Zf(10,10) ! ARRAYS FOR FORCE LOCATION ITERATIONS
3535 DIM Zw1(5),Xst(10)
3536 ! WATERLINE INTERPOLATION VALUES
3537 DATA .879,1.319,1.539,1.759,1.869,1.979
3538 DATA .879,1.319,1.539,1.759,1.869,1.979,2.088,2.198
3539 DATA .879,1.319,1.539,1.759,1.869,1.979,2.088,2.198,2.298
3540 DATA .879,1.319,1.539,1.759,1.869,1.979,2.088,2.198,2.298,2.398
3541 DATA .879,1.319,1.539,1.759,1.869,1.979,2.088,2.198,2.298,2.398
3542 READ Xw1(*),Xw2(*),Xw3(*),Xw4(*),Xw5(*)
3543 !
3544 DATA .461,.403,.334,.228,.157,.076 ! CASE 1
3545 DATA .472,.427,.371,.282,.225,.158,.085,.012 ! CASE 2
3546 DATA .476,.436,.386,.304,.252,.191,.126,.061,.013 ! CASE 3

```



```

3599 I X,Y: DATA ARRAYS
3600 I N: NO OF DATA POINTS
3601 I A: AUGMENTED MATRIX OF COEFF RETURNED FROM PROGRAM
3602 I S: ARRAY OF 2nd DERIVATIVE VALUES AT DATA POINTS
3603 I Iend: TYPE OF END CONDITION
3604 I 1: LINEAR
3605 I 2: PARABOLIC
3606 I 3: CUBIC ENDS
3607 INTEGER Nm2,Nm1,I,J
3608 ALLOCATE A(N,4)
3609 IF Iend<1 OR Iend>3 THEN
3610 ALPHA ON
3611 INPUT "Iend VALUE INCORRECTLY SPECIFIED. INPUT 1,2,OR 3",Iend
3612 GOTO 3609
3613 END IF
3614 Nm2=N-2
3615 Nm1=N-1
3616 Dx1=X(2)-X(1)
3617 Dy1=(Y(2)-Y(1))/Dx1*6
3618 FOR I=1 TO Nm2
3619 Dx2=X(I+2)-X(I+1)
3620 Dy2=(Y(I+2)-Y(I+1))/Dx2*6
3621 A(I,1)=Dx1
3622 A(I,2)=2*(Dx1+Dx2)
3623 A(I,3)=Dx2
3624 A(I,4)=Dy2-Dy1
3625 Dx1=Dx2
3626 Dy1=Dy2
3627 NEXT I
3628 IF Iend=2 THEN
3629 A(1,2)=A(1,2)+X(2)-X(1)
3630 A(Nm2,2)=A(Nm2,2)+X(N)-X(Nm1)
3631 END IF
3632 IF Iend=3 THEN
3633 Dx1=X(2)-X(1)
3634 Dx2=X(3)-X(2)
3635 A(1,2)=(Dx1+Dx2)*(Dx1+2*Dx2)/Dx2
3636 A(1,3)=(Dx2*Dx2-Dx1*Dx1)/Dx2
3637 Dxn2=X(Nm1)-X(Nm2)
3638 Dxn1=X(N)-X(Nm1)
3639 A(Nm2,1)=(Dxn2*Dxn2-Dxn1*Dxn1)/Dxn2
3640 A(Nm2,2)=(Dxn1+Dxn2)*(Dxn1+2*Dxn2)/Dxn2
3641 END IF
3642 FOR I=2 TO Nm2 I A(*) IS AUGMENTED TRIDIAG WHICH IS NOW SOLVED
3643 A(I,2)=A(I,2)-A(I,1)/A(I-1,2)*A(I-1,3)
3644 A(I,4)=A(I,4)-A(I,1)/A(I-1,2)*A(I-1,4)
3645 NEXT I
3646 A(Nm2,4)=A(Nm2,4)/A(Nm2,2)
3647 FOR I=2 TO Nm2
3648 J=Nm1-I
3649 A(J,4)=(A(J,4)-A(J,3)*A(J+1,4))/A(J,2)
3650 NEXT I

```

```

3651 FOR I=1 TO Nm2
3652   S(I+1)=A(I,4)
3653 NEXT I
3654 SELECT Iend
3655   CASE 1
3656     S(1)=0
3657     S(N)=0
3658   CASE 2
3659     S(1)=S(2)
3660     S(N)=S(N-1)
3661   CASE 3
3662     S(1)=((Dx1+Dx2)*S(2)+Dx1*S(3))/Dx2
3663     S(N)=((Dx2+Dxn1)*S(Nm1)-Dxn1*S(Nm2))/Dxn2
3664 END SELECT
3665 DEALLOCATE A(*)
3666 SUBEND
3667 !.....
3668 SUB Polyregress(X(*),Y(*),A(*),INTEGER I0,I1,Order)
3669 ! COMPUTE THE N+1 COEFF OF THE N-TH ORDER POLY FIT THRU X-Y DATA
3670 ! R BROWN JULY 1986
3671 !
3672 ! X(*),Y(*)   INPUT DATA
3673 ! A(*)       RETURNED VECTOR OF ORDER+1 COEFFICIENTS, A(1)=CONSTANT TERM
3674 ! I0,I1      LOWER,UPPER INDICES FOR INPUT DATA
3675 ! ORDER      ORDER OF POLYNOMIAL FIT TO DATA
3676 !
3677 OPTION BASE 1
3678 ALLOCATE An(Order+1,Order+1),Aninv(Order+1,Order+1),C(Order+1),Xn(I1-I0+1)
3679 MAT Xn= (1)           ! SET XN TO BE UNITY VECTOR
3680 MAT C= (0)
3681 MAT An= (0)
3682 FOR I=1 TO Order+1    ! FILL FIRST COLUMN OF AN MATRIX AND C VECTOR
3683   FOR J=I0 TO I1
3684     An(I,1)=An(I,1)+Xn(J)
3685     C(I)=C(I)+Y(J)*Xn(J)
3686     Xn(J)=Xn(J)*X(J)
3687   NEXT J
3688 NEXT I
3689 FOR I=2 TO Order+1    ! LAST ROW OF AN
3690   FOR J=I0 TO I1
3691     An(Order+1,I)=An(Order+1,I)+Xn(J)
3692     Xn(J)=Xn(J)*X(J)
3693   NEXT J
3694 NEXT I
3695 FOR J=2 TO Order+1    ! FILL IN THE REST BY SHIFTING EXISTING DATA OVER
3696   FOR I=1 TO Order
3697     An(I,J)=An(I+1,J-1)
3698   NEXT I
3699 NEXT J
3700 MAT Aninv= INV(An)
3701 MAT A= Aninv*C
3702 DEALLOCATE An(*),Aninv(*),C(*),Xn(*)

```



```

3703 SUBEND
3704 ! !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3705 SUB Spline_coeff(X(*),Y(*),S(*),A,B,C,D,INTEGER J)
3706 ! RETURNS THE CUBIC SPLINE COEFFICIENTS A,B,C,D FOR INTERVAL J
3707 ! USES THE VALUES OF X AND Y BORDERING THE INTERVAL
3708 ! R BROWN JULY 1986
3709   Dx=X(J+1)-X(J)
3710   A=(S(J+1)-S(J))/(6*Dx)
3711   B=S(J)/2
3712   C=(Y(J+1)-Y(J))/Dx-(2*Dx*S(J)+Dx*S(J+1))/6
3713   D=Y(J)
3714 SUBEND
3715 ! .....
3716 SUB Linscale(A(*),Amin,Amax,Stick,INTEGER I0,I1) ! FINDING SCALES ON
3717           ! THE Y-AXIS OF THE PLOTS
3718 IF Amin=0 AND Amax=0 THEN GOSUB Findmaxandmin
3719 GOSUB Findrange
3720 GOSUB Findnicetick
3721 GOSUB Scalemaxandmin
3722 SUBEXIT
3723 !
3724 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3725 !
3726 Findmaxandmin:                                ! FIND MAX AND MIN VALUE OF DATA
3727   Amax=-9.E+99
3728   Amin=9.E+99
3729   INTEGER I
3730   FOR I=I0 TO I1                                ! FIND MAX AND MIN BETWEEN INDICES I0,I1
3731     IF A(I)>Amax THEN Amax=A(I)
3732     IF A(I)<Amin THEN Amin=A(I)
3733   NEXT I
3734   RETURN
3735 !
3736 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3737 !
3738 Findrange: !
3739   Range=Amax-Amin
3740   IF Range=0 THEN
3741     Amax=Amax+10
3742     Amin=Amin-10
3743     Range=Amax-Amin
3744   END IF
3745   RETURN
3746 !
3747 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3748 !
3749 Findnicetick:                                ! RETURNS A NICE NO FOR TICK SPACING
3750   Inc=10*(INT(LGT(Range))-2)                ! IF 100<=RANGE<1000 THEN Inc=1
3751   Inc: !
3752   Inc=Inc*10
3753   IF Range>6*Inc THEN Try12
3754   Stick=Inc                                ! TICKS OF ...,1,10,100,...

```

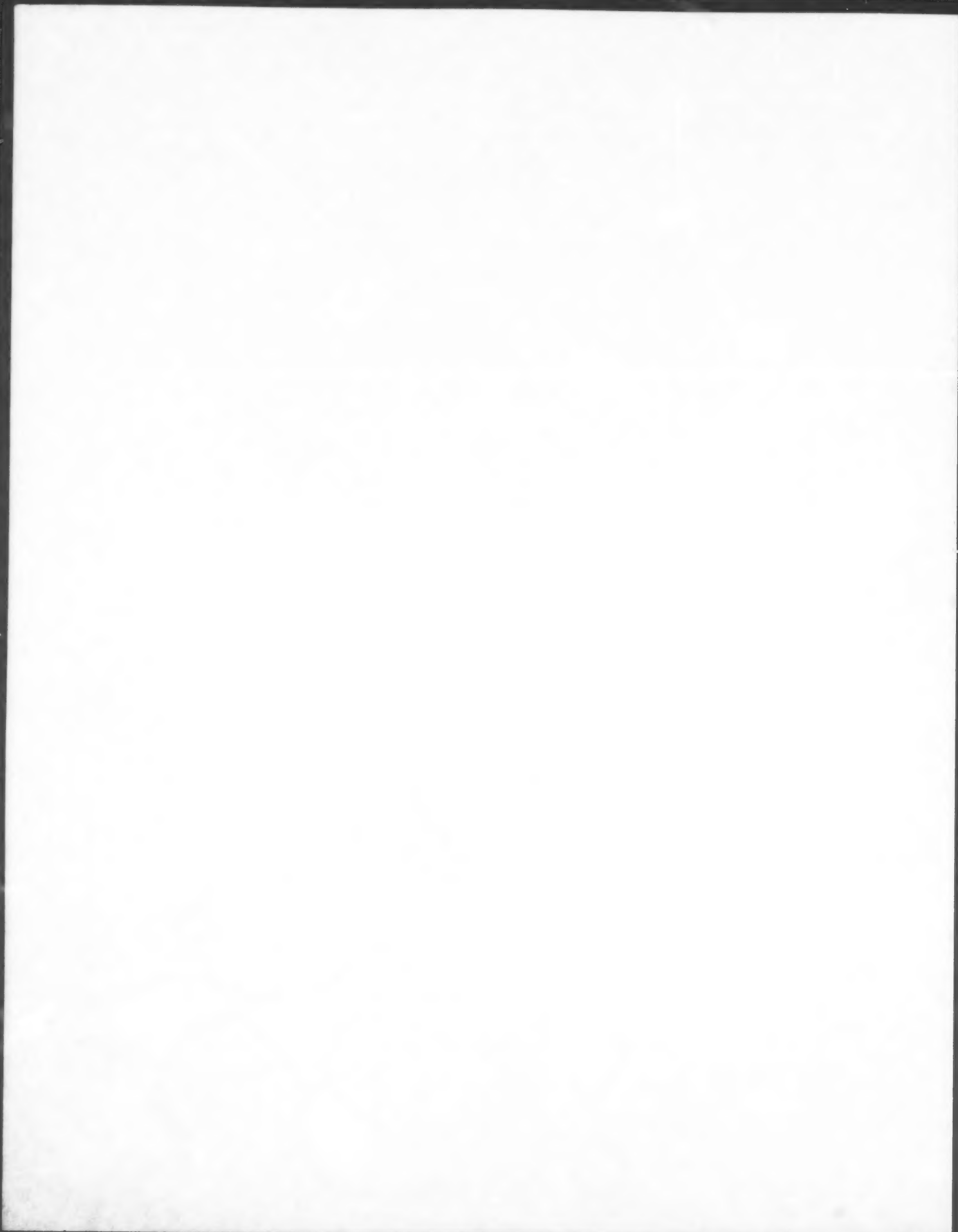
```

3755 RETURN
3756 Try12:|
3757 IF Range>12*Inc THEN Try30
3758 Stick=2*Inc | TICKS OF ...,2,20,200,...
3759 RETURN
3760 Try30:|
3761 IF Range>30*Inc THEN Inc
3762 Stick=5*Inc | TICKS OF ...,5,50,500,...
3763 RETURN
3764 |
3765 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3766 |
3767 Scalemaxandmin: | FIND SCALE EVENLY DIVISIBLE BY STICK
3768 IF Amax>=0 THEN
3769 Amax=Amax DIV Stick*Stick+Stick
3770 ELSE
3771 Amax=Amax DIV Stick*Stick
3772 END IF
3773 IF Amin>=0 THEN
3774 Amin=Amin DIV Stick*Stick
3775 ELSE
3776 Amin=Amin DIV Stick*Stick-Stick
3777 END IF
3778 RETURN
3779 |
3780 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!
3781 |
3782 SUBEND
3783 !!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!

```

APPENDIX B

CALCULATING THE CALIBRATION RIG PARAMETERS



APPENDIX B: CALCULATING THE CALIBRATION RIG PARAMETERS

The basis for the equations used to find the calibration rig parameters will be outlined here. If the applied force is normal the calibration angle α_c equals α , the waterplane angle at the point x, z on the hull when the load is being applied. Referring to Figure B.1 the angles α and β , where β is the flare angle at x, z , define a plane tangent to the hull. Arm r_2 is in the plane of the main deck which is the origin of the z axis. r_2' is normal to the waterplane at point x, z . r_2' extends from the centerline until it contacts the plane tangent to the hull. r_3' is the distance from the end of r_2' to the point x, z . It lies in the tangential plane.

From Figure B.1 it can be seen that

$$y' = z \tan \beta \quad (B.1)$$

and looking at the x - y plane in Figure B.2

$$r_2' - y/\cos\alpha = y'\cos\alpha \quad (B.2)$$

Looking at the plane in which r_2' and r_3' lie in Figure 3.3 it can be seen that

$$\tan\theta = z/y'\cos\alpha \quad (B.3)$$

where θ is the angle between r_2' and r_3' .

Substituting (1) into (3) we have a definition for θ in terms of α and β

$$\tan\theta = 1/\tan\beta\cos\alpha \quad (B.4)$$

and from this a formula for r_3'

$$r_3' = z/\cos\theta \quad (B.5)$$

Rearranging (3) in terms of $y'\cos\alpha$ and substituting into (2), an expression for r_2' can be found

$$r_2' = y/\cos\alpha + z/\tan\theta \quad (B.6)$$

Examining Figure B.1 it can be seen that

$$r_1 = x - y \tan \alpha \quad (B.7)$$

Now r_2 and r_3 have to be found from r_2' and r_3' . If the calibration rig is mounted a distance d from the 24.75' W.L. as shown in Figure B.4 and the point where the calibration rig applies its load is a distance h from the hinge point then

$$r_2 = r_2' + h/\sin \theta + d/\tan \theta \quad (B.8)$$

$$r_3 = r_3' + h/\tan \theta + d/\sin \theta \quad (B.9)$$

The actual values of h and d were respectively, 0.052m and 0.3138m.

Equations B.4 to B.9 were incorporated into a computer subroutine which when given x , y , z , α and β would output the calibration rig parameters r_1 , r_2 , r_3 , α_c and θ . This calibration rig set-up algorithm as the computer subroutine has been called was used in conjunction with the hull interpolation routine described in Section 3.4 so that the calibration rig parameters could be found in one step.

Calculating the calibration rig angles α and β if a friction force as well as a normal force was to be applied was done as follows:

$$\vec{F} = -F_n \vec{n} + \mu F_n \vec{e} \quad (B.10)$$

It is obvious that if n_1 , n_2 and n_3 are known from the hull angles, e_1 , e_2 and e_3 must be determined to find the direction of the total force $\vec{F}$.

Two options for applying the friction force were allowed: friction acting in the x-y plane and friction acting in the x-z plane. For friction acting in the x-y plane as shown in Figure B.5A and a friction vector $\vec{e}$ with

$$\vec{e} = -e_1 \vec{i} + e_2 \vec{j} + e_3 \vec{k}$$

then $\vec{e}$ must have components

$$\begin{aligned} e_1 &= \cos \alpha \\ e_2 &= \sin \alpha \end{aligned} \quad (B.11)$$

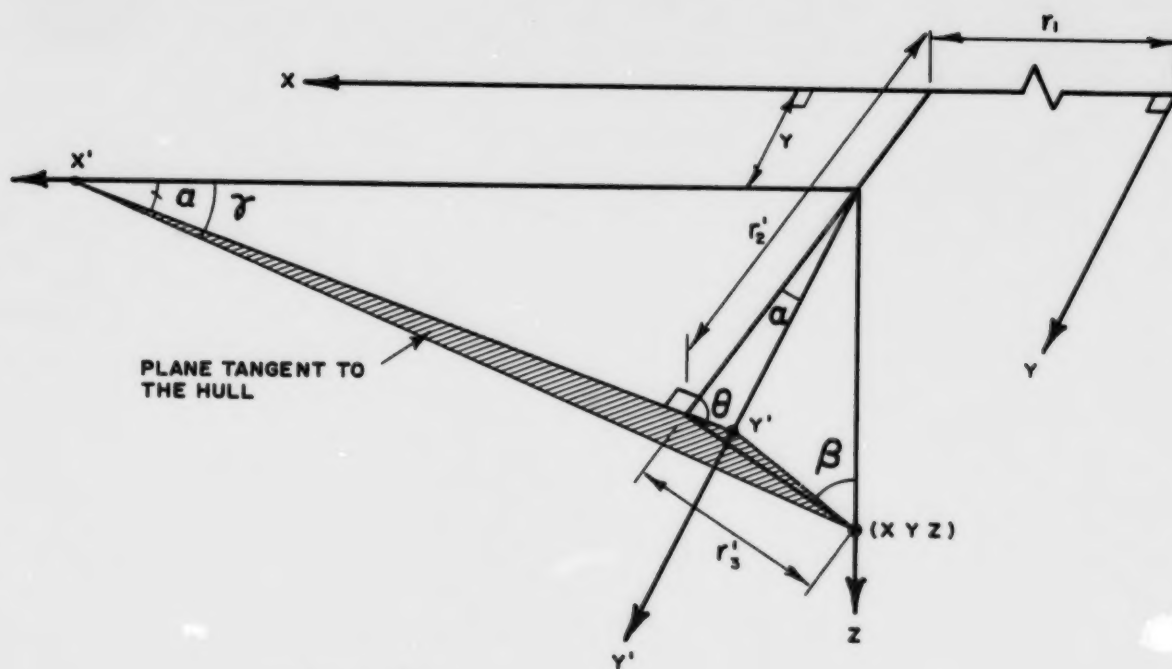


Figure B.1

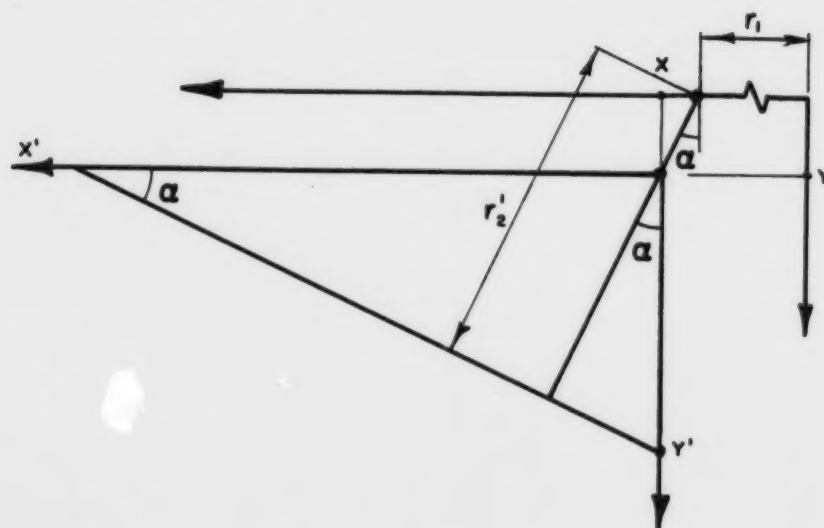


Figure B.2 X - Y PLANE

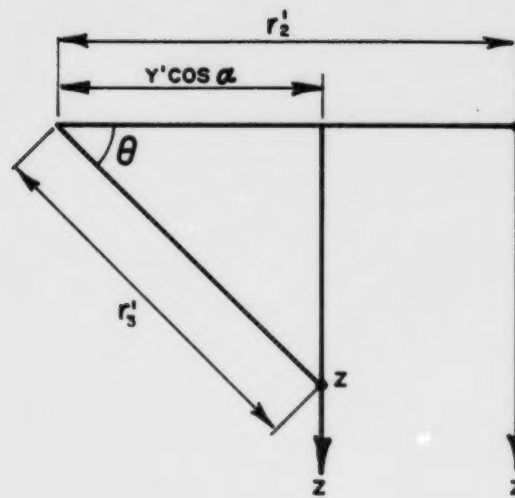


Figure B.3 $r'_2 - r'_3$ PLANE

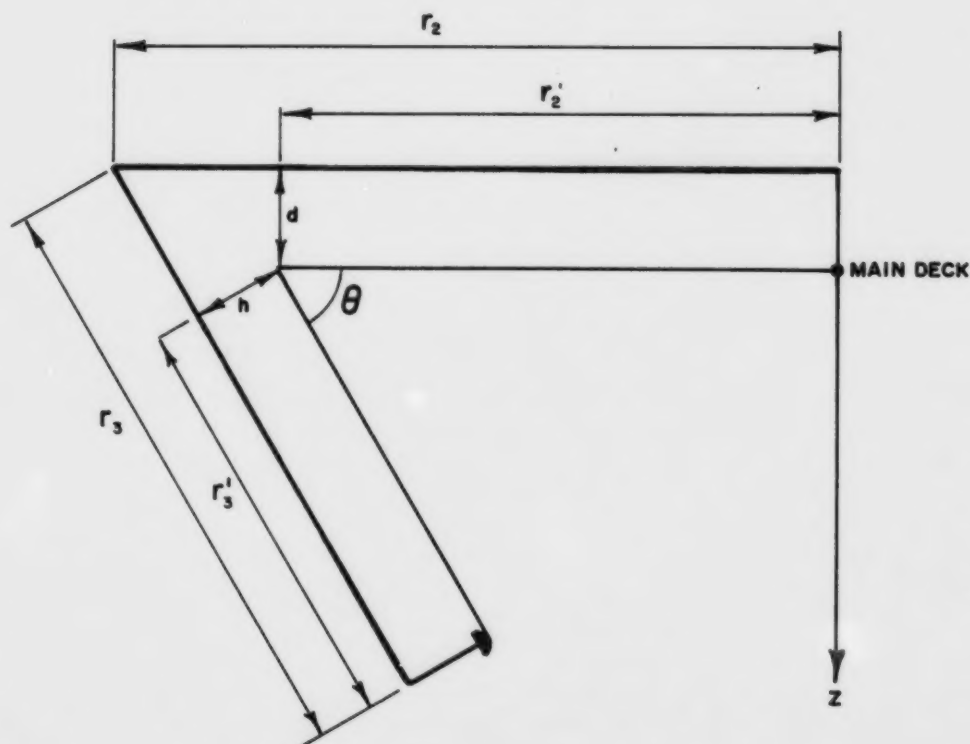


Figure B.4 FINDING r_2 and r_3

For a friction force acting in the x-z plane then as shown in Figure B.5B then

$$\begin{aligned} e_1 &= \sin\beta \\ e_2 &= 0 \\ e_3 &= \cos\beta \end{aligned} \tag{B.12}$$

The values for e_1 , e_2 and e_3 were calculated depending on the friction direction chosen. Then the angles of the total force and therefore of the calibration rig since it must apply the load at the angles of the total force are:

$$\begin{aligned} \alpha_c &= \arctan (F_x/F_y) = \arctan \left(\frac{n_1 + \mu e_1}{n_2 - \mu e_2} \right) \\ \beta_c &= \arctan (F_z/F_y) = \arctan \left(\frac{n_3 - \mu e_3}{n_2 - \mu e_2} \right) \end{aligned} \tag{B.13}$$

The angles α_c and β_c were then substituted into equations B.4 - B.9 replacing α and β respectively, and the calibration rig parameters r_1 , r_2 , r_3 and θ were calculated accordingly.

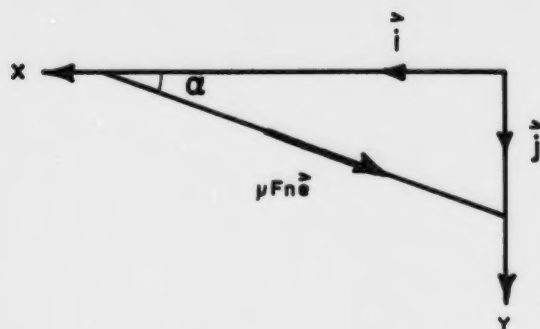


Figure B.5A A FRICTION FORCE IN THE X - Y PLANE

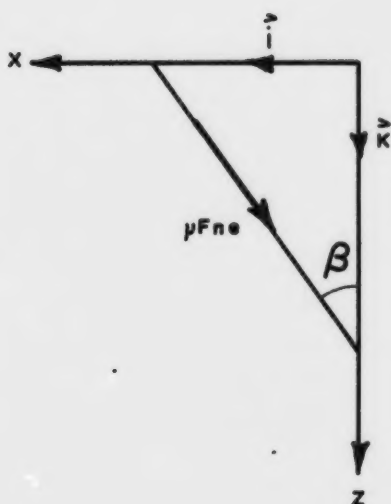


Figure B.5B A FRICTION FORCE IN THE X - Z PLANE

APPENDIX C

RESOLVING CALIBRATION RIG MEASUREMENTS

APPENDIX C: RESOLVING CALIBRATION RIG MEASUREMENTS

The triaxial calibration rig transducer consisted of three force transducers bolted together so that they formed an orthogonal system. The three transducers have been labelled NOR, T_V and T_1 as shown in Figure C.1.

The direction on the transducers in Figure C.1 indicates the direction of the force measured when a positive voltage was recorded by the transducer.

In the vertical plane normal to the hull only transducers NOR and T_V act. They can be resolved into two components, F_z the force in the z direction and F_θ the force in the horizontal plane normal to the waterline. From Figure C.2 it can be seen that

$$F_z = - \text{NOR} \cos\theta - T_V \sin\theta \quad (\text{C.1})$$

$$F_\theta = - \text{NOR} \sin\theta + T_V \cos\theta \quad (\text{C.2})$$

where θ is defined in equation (B.3).

In the x-y plane F_θ as well as T_1 act as shown in Figure C.3. The resulting forces in the x and y direction as shown in Figure C.3 are

$$F_x = F_\theta \sin\alpha_c - T_1 \cos\alpha_c \quad (\text{C.3})$$

$$F_y = F_\theta \cos\alpha_c + T_1 \sin\alpha_c \quad (\text{C.4})$$

substituting in (C.2) then

$$F_x = (-\text{NOR}\sin\theta + T_V \cos\theta) \sin\alpha_c + T_1 \cos\alpha_c \quad (\text{C.5})$$

$$F_y = (-\text{NOR}\sin\theta + T_V \cos\theta) \cos\alpha_c - T_1 \sin\alpha_c \quad (\text{C.6})$$

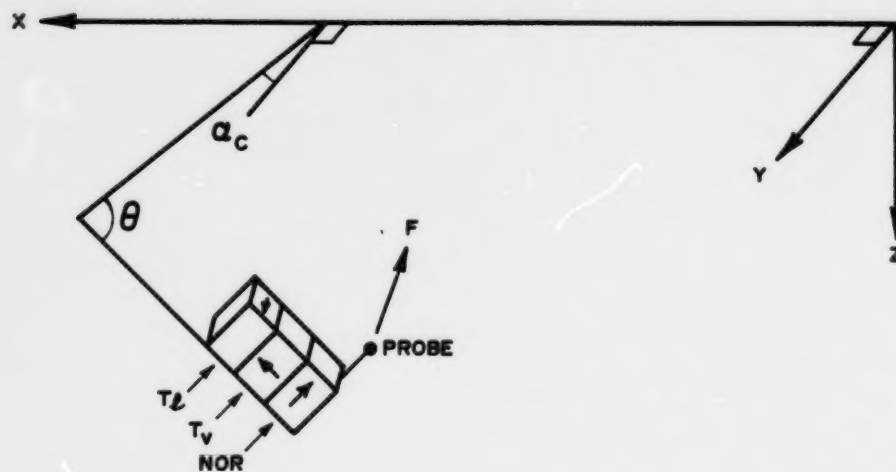


Figure C.1 ARRANGEMENT OF CALIBRATION RIG TRANSDUCERS

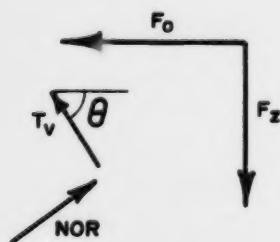


Figure C.2 F_0 and F_z

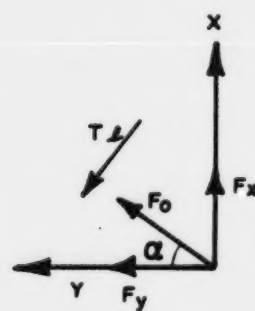


Figure C.3 F_x and F_y

Normal and Friction Forces:

When the calibration rig is normal to the model then the normal force is obviously

$$\begin{aligned} F_n &= \text{NOR} \\ \alpha_c &= \alpha \\ \beta_c &= \beta \end{aligned} \tag{C.7}$$

where F_n is acting in the direction opposing the normal as outlined in Chapter 3. The friction force, μF_n , when the calibration rig is normal to the hull is

$$\mu F_n = \sqrt{T_V^2 + T_1^2} \tag{C.8}$$

If the friction force has the vector e where

$$e = -e_1 \vec{i} + e_2 \vec{j} + e_3 \vec{k} \tag{C.9}$$

and since NOR is applying the normal load when the calibration rig is normal to the hull then equating (C.1) (C.2) and (C.3) to (3.3) we have

$$-\text{NOR} \sin \theta \sin \alpha + T_V \cos \theta \sin \alpha - T_1 \cos \alpha = -F_n (n_1 + \mu e_1) \tag{C.10a}$$

$$-\text{NOR} \sin \theta \cos \alpha + T_V \cos \theta \cos \alpha + T_1 \sin \alpha = -F_n (n_2 - \mu e_2) \tag{C.10b}$$

$$-\text{NOR} \cos \theta - T_V \sin \theta = -F_n (n_3 - \mu e_3) \tag{C.10c}$$

then since $\mu F_n = F_f$ we have

$$e_1 = \frac{-T_V \cos \theta \sin \alpha + T_1 \cos \alpha}{\mu F_n} \quad (C.11a)$$

$$e_2 = \frac{T_V \cos \theta \cos \alpha + T_1 \sin \alpha}{\mu F_n} \quad (C.11b)$$

$$e_3 = -\frac{T_V \sin \theta}{\mu F_n} \quad (C.11c)$$

The friction direction ψ as defined in section 3.5 becomes

$$\psi = \tan^{-1} \frac{-T_V \cos \theta \sin \alpha + T_1 \cos \alpha}{T_V \sin \theta} \quad (C.12)$$

APPENDIX D

**RESULTS OF EXTERNAL SEGMENT CALIBRATIONS
AND THE CALIBRATION RIG VERIFICATION TESTS**

D.1 SEGMENT 1 CALIBRATION RESULT SHEETS

This appendix contains the results of external calibrations at segment 1 performed with the calibration rig. The procedure for these tests and an explanation of the calibration sheet format is given in Section 4, Volume I. The calibrations are listed in order of increasing calibration point number. The number in the file name indicates the calibration position. A file name beginning with a "W" indicates an "in-water" calibration whereas one without is an "in-air" calibration.



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PROJECT 1566C

SEGMENT NUMBER 1 FILE NAME POS_21
 NOV 18 CALIBRATION POSITION 21

TRANSDUCER	READING (N)
R-11	4.47
H-11	-.19
H-12	9.28
V-11	11.17
V-12	21.01
V-13	-14.79
RV-1	0.00
HV-1	-.20
T'V	5.42
T'L	-1.83
NOR	16.11
RV-1X	0.00
HV-1Y	-.20

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	2.49	4.47	80.	2.0
Y	8.20	8.89	8.	.7
Z	14.80	17.18	16.	2.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.43 X PLANE
 C2= 1.47 Y PLANE
 C3= -.22 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION : X=	2.088	2.088	-.000 m
Z=	.011	.008	-.003 m
WATERPLANE ANGLE	29.	29.	-0. DEG
FLARE ANGLE	46.	43.	-3. DEG
TOTAL FORCE	17.098	19.859	16.1 %
NORMAL FORCE	16.111	18.580	15.3 %
FRICTION FACTOR	.355	.377	
FRICTION FORCE	5.723	7.010	22.5 %
FRICTION DIRECTION	109.	93.	-15. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 18 SEGMENT NUMBER 1 FILE NAME POS_22
 CALIBRATION POSITION 22

TRANSDUCER	READING (N)
R-11	8.05
H-11	12.28
H-12	3.09
V-11	21.76
V-12	15.80
V-13	-14.06
RV-1	.85
HV-1	.60
T'V	3.48
T'L	-3.20
NOR	25.93
RV-1X	.49
HV-1Y	.60

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	5.05	8.55	69.	3.5
Y	15.65	15.98	2.	.3
Z	20.60	24.95	21.	4.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.22 X PLANE
 C2= 4.16 Y PLANE
 C3= -2.52 Z PLANE

LOCATION	APPLIED	MEASURED	ERROR
:X=	2.198	2.172	-.026 m
Z=	.011	.014	.003 m
WATERPLANE ANGLE	29.	29.	-0. DEG
FLARE ANGLE	48.	49.	0. DEG

TOTAL FORCE	26.360	30.838	17.0 %
NORMAL FORCE	25.933	30.445	17.4 %
FRICTION FACTOR	.182	.161	
FRICTION FORCE	4.724	4.903	3.8 %
FRICTION DIRECTION	133.	93.	-40. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 1 FILE NAME POS_23
NOV 18 CALIBRATION POSITION 23

TRANSDUCER	READING (N)
R-11	8.59
H-11	23.04
H-12	-7.73
V-11	35.97
V-12	2.40
V-13	-6.94
RV-1	.34
HV-1	-.20
T'V	5.55
T'L	-.46
NOR	29.73
RV-1X	.20
HV-1Y	-.20

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	6.65	8.79	32.	2.1
Y	14.11	15.11	7.	1.0
Z	25.92	31.57	22.	5.7

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -1.33 X PLANE
C2= 8.01 Y PLANE
C3= -4.15 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.298	2.257	-.041 m
	Z=	.011	.011	0.000 m
WATERPLANE ANGLE		27.	29.	2. DEG
FLARE ANGLE		52.	50.	-1. DEG

TOTAL FORCE	30.247	36.083	19.3 %
NORMAL FORCE	29.731	34.910	17.4 %
FRICTION FACTOR	.187	.261	
FRICTION FORCE	5.567	9.125	63.9 %
FRICTION DIRECTION	95.	88.	-7. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

NOV 18 SEGMENT NUMBER 1 FILE NAME POS_25
 CALIBRATION POSITION 25

TRANSDUCER	READING (N)
R-11	11.10
H-11	-8.76
H-12	27.93
V-11	10.98
V-12	51.81
V-13	-23.56
RV-1	-.34
HV-1	0.00
T'V	9.73
T'L	-3.20
NOR	37.72
RV-1X	-.20
HV-1Y	0.00

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	7.35	10.90	48.	3.5
Y	19.27	19.17	-1.	-.1
Z	33.20	38.89	17.	5.7

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -5.57 X PLANE
 C2= 1.54 Y PLANE
 C3= .93 Z PLANE

LOCATION	APPLIED	MEASURED	ERROR
:X=	2.040	2.049	.009 m
Z=	.027	.033	.006 m
WATERPLANE ANGLE	30.	30.	0. DEG
FLARE ANGLE	48.	50.	2. DEG

TOTAL FORCE	39.087	44.706	14.4 %
NORMAL FORCE	37.722	43.262	14.7 %
FRICTION FACTOR	.271	.260	
FRICTION FORCE	10.237	11.269	10.1 %
FRICTION DIRECTION	108.	91.	-17. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 19 SEGMENT NUMBER 1 FILE NAME WPOS_25
CALIBRATION POSITION 25

TRANSDUCER	READING (N)
R-11	7.61
H-11	-5.71
H-12	19.77
V-11	6.47
V-12	32.01
V-13	-12.97
RV-1	-.17
HV-1	.20
T'V	2.05
T'L	-1.37
NOR	28.46
RV-1X	-.10
HV-1Y	.20

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	8.28	7.51	-9.	-.8
Y	17.21	14.25	-17.	-3.0
Z	21.25	25.54	20.	4.3

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -3.26 X PLANE
C2= 1.15 Y PLANE
C3= .51 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.040	2.056	.016 m
	Z=	.027	.038	.011 m
WATERPLANE ANGLE	30.		31.	1. DEG
FLARE ANGLE	48.		51.	3. DEG

TOTAL FORCE	28.572	30.195	5.7 %
NORMAL FORCE	28.465	29.655	4.2 %
FRICTION FACTOR	.087	.192	
FRICTION FORCE	2.469	5.687	130.3 %
FRICTION DIRECTION	124.	98.	-26. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 17 SEGMENT NUMBER 1 FILE NAME POS_26
CALIBRATION POSITION 26

TRANSDUCER	READING (N)
R-11	10.83
H-11	-.38
H-12	19.77
V-11	16.46
V-12	33.41
V-13	-19.36
RV-1	2.39
HV-1	.40
T'V	4.22
T'L	-1.83
NOR	33.25
RV-1X	1.38
HV-1Y	.40

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	8.10	12.21	51.	4.1
Y	17.88	19.79	11.	1.9
Z	27.23	33.31	22.	6.1

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -3.62 X PLANE
C2= 3.07 Y PLANE
C3= -.45 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.088	2.104	.016 m
	Z=	.027	.033	.006 m
WATERPLANE ANGLE		30.	30.	0. DEG
FLARE ANGLE		51.	53.	2. DEG

TOTAL FORCE	33.569	40.619	21.0 %
NORMAL FORCE	33.252	40.365	21.4 %
FRICTION FACTOR	.138	.112	
FRICTION FORCE	4.602	4.533	-1.5 %
FRICTION DIRECTION	113.	81.	-32. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 19 SEGMENT NUMBER 1 FILE NAME WPOS_26
CALIBRATION POSITION 26

TRANSDUCER	READING (N)
R-11	11.90
H-11	-3.43
H-12	18.39
V-11	8.72
V-12	26.51
V-13	-10.04
RV-1	.51
HV-1	.40
T'V	2.23
T'L	.91
NOR	26.10
RV-1X	.30
HV-1Y	.40

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	8.79	12.20	39.	3.4
	Y	13.56	15.36	13.	1.8
	Z	20.64	26.10	26.	5.5

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.64 X PLANE
C2= 1.94 Y PLANE
C3= .29 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.088	2.093	.005 m
	Z=	.027	.040	.013 m
WATERPLANE ANGLE		30.	30.	1. DEG
FLARE ANGLE		51.	54.	3. DEG
TOTAL FORCE		26.213	32.648	24.5 %
NORMAL FORCE		26.101	32.462	24.4 %
FRICTION FACTOR		.092	.107	
FRICTION FORCE		2.414	3.479	44.1 %
FRICTION DIRECTION FROM THE HORIZONTAL		68.	38.	-29. DEG

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PROJECT 1566C

NOV 17 SEGMENT NUMBER 1 FILE NAME POS_27
CALIBRATION POSITION 27

TRANSDUCER	READING (N)
R-11	12.97
H-11	12.76
H-12	3.27
V-11	30.58
V-12	16.80
V-13	-10.14
RV-1	1.20
HV-1	.60
T'V	10.02
T'L	-3.65
NOR	38.52
RV-1X	.69
HV-1Y	.60

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	5.90	13.66	132.	7.8
	Y	17.03	16.63	-2.	-.4
	Z	35.67	39.04	9.	3.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1=	-2.67	X PLANE		
C2=	7.07	Y PLANE		
C3=	-2.37	Z PLANE		
LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.198	2.191	-.007 m
	Z=	.027	.029	.002 m
WATERPLANE ANGLE		31.	32.	1. DEG
FLARE ANGLE		53.	54.	0. DEG
TOTAL FORCE		39.967	44.579	11.5 %
NORMAL FORCE		38.518	43.513	13.0 %
FRICTION FACTOR		.277	.223	
FRICTION FORCE		10.662	9.694	-9.1 %
FRICTION DIRECTION	110.		72.	-38. DEG
FROM THE HORIZONTAL				

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 19 SEGMENT NUMBER 1 FILE NAME WPOS_27
 CALIBRATION POSITION 27

TRANSDUCER	READING (N)
R-11	10.74
H-11	11.43
H-12	4.81
V-11	20.19
V-12	12.20
V-13	-6.03
RV-1	1.03
HV-1	.20
T'V	1.83
T'L	.46
NOR	30.43
RV-1X	.59
HV-1Y	.20

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	9.89	11.33	15.	1.4
Y	15.69	16.44	5.	.7
Z	24.20	27.59	14.	3.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -1.67 X PLANE
 C2= 4.80 Y PLANE
 C3= -2.23 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION : X=	2.198	2.187	-.011 m
Z=	.027	.030	.003 m
WATERPLANE ANGLE	31.	32.	1. DEG
FLARE ANGLE	53.	54.	1. DEG
TOTAL FORCE	30.492	34.055	11.7 %
NORMAL FORCE	30.433	33.932	11.5 %
FRICTION FACTOR	.062	.085	
FRICTION FORCE	1.890	2.901	53.5 %
FRICTION DIRECTION	76.	73.	-4. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 18 SEGMENT NUMBER 1 FILE NAME POS_28
CALIBRATION POSITION 28

TRANSDUCER	READING (N)
R-11	5.55
H-11	26.09
H-12	-8.42
V-11	33.32
V-12	-3.20
V-13	-2.47
RV-1	-.17
HV-1	-.20
T'V	5.29
T'L	-1.37
NOR	31.30
RV-1X	-.10
HV-1Y	-.20

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	5.70	5.45	-4.	-.2
Y	15.94	17.47	10.	1.5
Z	26.89	27.28	1.	.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1=	-.46	X PLANE		
C2=	7.75	Y PLANE		
C3=	-4.95	Z PLANE		
LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.298	2.288	-.010 m
	Z=	.027	.022	-.005 m
WATERPLANE ANGLE		24.	26.	2. DEG
FLARE ANGLE		51.	53.	2. DEG
TOTAL FORCE		31.776	32.850	3.4 %
NORMAL FORCE		31.303	32.491	3.8 %
FRICTION FACTOR		.174	.149	
FRICTION FORCE		5.462	4.841	-11.4 %
FRICTION DIRECTION	105.		126.	22. DEG
FROM THE HORIZONTAL				

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 1 FILE NAME POS_29
NOV 18 CALIBRATION POSITION 29

TRANSDUCER	READING (N)
R-11	7.70
H-11	-.76
H-12	15.81
V-11	8.62
V-12	35.11
V-13	-7.12
RV-1	.85
HV-1	.60
T'V	10.49
T'L	-4.11
NOR	36.95
RV-1X	.49
HV-1Y	.60

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	4.62	8.19	77.	3.6
Y	15.88	15.65	-1.	-.2
Z	34.91	38.07	9.	3.2

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -4.19 X PLANE
C2= 3.05 Y PLANE
C3= -.38 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	2.088	2.089	.001 m
Z=	.042	.041	-.001 m
WATERPLANE ANGLE	31.	31.	-0. DEG
FLARE ANGLE	54.	54.	-0. DEG
TOTAL FORCE	38.629	41.964	8.6 %
NORMAL FORCE	36.951	40.397	9.3 %
FRICTION FACTOR	.305	.281	
FRICTION FORCE	11.264	11.360	.8 %
FRICTION DIRECTION FROM THE HORIZONTAL	111.	95.	-17. DEG

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PROJECT 1566C

NOV 19 SEGMENT NUMBER 1 FILE NAME WPOS_29
 CALIBRATION POSITION 29

TRANSDUCER	READING (N)
R-11	9.31
H-11	-1.33
H-12	13.23
V-11	4.70
V-12	18.60
V-13	-4.57
RV-1	.68
HV-1	.30
T'V	1.03
T'L	.91
NOR	22.52
RV-1X	.39
HV-1Y	.30

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	7.83	9.70	24.	1.9
Y	11.45	12.20	7.	.8
Z	17.79	19.73	11.	1.9

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -1.84 X PLANE
 C2= 1.44 Y PLANE
 C3= .01 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.088	2.095	.007 m
	Z=	.042	.044	.002 m
WATERPLANE ANGLE		31.	31.	0. DEG
FLARE ANGLE		54.	54.	0. DEG

TOTAL FORCE	22.563	25.142	11.4 %
NORMAL FORCE	22.521	25.038	11.2 %
FRICTION FACTOR	.061	.091	
FRICTION FORCE	1.376	2.287	66.3 %
FRICTION DIRECTION	48.	24.	-25. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 18 SEGMENT NUMBER 1 FILE NAME POS_30
 CALIBRATION POSITION 30

TRANSDUCER	READING (N)
R-11	7.52
H-11	11.81
H-12	1.03
V-11	13.72
V-12	7.40
V-13	4.38
RV-1	1.11
HV-1	1.00
T'V	4.32
T'L	0.00
NDR	30.10
RV-1X	.64
HV-1Y	1.00

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	6.15	8.16	33.	2.0
Y	12.84	13.84	8.	1.0
Z	26.87	27.62	3.	.8

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -1.30 X PLANE
 C2= 4.79 Y PLANE
 C3= -2.37 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.198	2.186	-.012 m
	Z=	.042	.042	0.000 m
WATERPLANE ANGLE		26.	31.	5. DEG
FLARE ANGLE		57.	56.	-0. DEG

TOTAL FORCE	30.406	31.949	5.1 %
NORMAL FORCE	30.097	31.674	5.2 %
FRICTION FACTOR	.144	.132	
FRICTION FORCE	4.323	4.182	-3.3 %
FRICTION DIRECTION	90.0	90.	90. DEG
FROM THE HORIZONTAL			0

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 1 FILE NAME POS_32
NOV 18 CALIBRATION POSITION 32

TRANSDUCER	READING (N)
R-11	-.18
H-11	-.57
H-12	11.17
V-11	.39
V-12	18.50
V-13	5.11
RV-1	.51
HV-1	.40
T'V	12.76
T'L	-3.20
NOR	30.29
RV-1X	.30
HV-1Y	.40

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	3.57	.12	-97.	-3.4
Y	11.00	11.00	-0.	-0.0
Z	30.93	24.92	-19.	-6.0

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.05 X PLANE
C2= 2.11 Y PLANE
C3= -.54 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	2.088	2.085	-.003 m
Z=	.072	.054	-.018 m
WATERPLANE ANGLE	34.	34.	0. DEG
FLARE ANGLE	53.	54.	1. DEG

TOTAL FORCE	33.025	27.243	-17.5 %
NORMAL FORCE	30.294	24.776	-18.2 %
FRICTION FACTOR	.434	.457	
FRICTION FORCE	13.150	11.328	-13.9 %
FRICTION DIRECTION	104.	123.	19. DEG
FROM THE HORIZONTAL			

D.2 SEGMENT 2 CALIBRATION RESULT SHEETS (WITH VERTICAL
 TRANSDUCER V₂₄ REMOVED)

This appendix contains the results of external calibrations of segment 2 performed with the calibration rig. These are the final calibrations, performed after all modifications to the segment were completed. The procedure for these tests and an explanation of the calibration sheet format is given in Section 4, Volume I. The calibrations are listed in order of increasing calibration point number. Three points were calibrated "in-air" and 6 points "in-water". The number in the file name indicates the calibration position. A file name beginning with a "W" indicates an "in-water" calibration whereas one without is an "in-air" calibration.



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PROJECT 1566C

NOV 18 SEGMENT NUMBER 2 FILE NAME POS_4C
 CALIBRATION POSITION 4

TRANSDUCER	READING (N)
R-21	2.87
R-22	.20
H-21	-4.94
H-22	20.62
H-23	.60
V-21	-2.38
V-22	4.07
V-23	17.58
V-25	.25
T'V	7.23
T'L	1.83
NOR	21.48

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	9.37	3.07	-67.	-6.3
Y	13.26	16.28	23.	3.0
Z	15.92	19.51	23.	3.6

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1=	-5.47	X PLANE		
C2=	1.79	Y PLANE		
C3=	1.13	Z PLANE		
LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.625	1.700	.075 m
	Z=	.027	.051	.024 m
WATERPLANE ANGLE		29.	23.	-6. DEG
FLARE ANGLE		29.	34.	4. DEG
TOTAL FORCE		22.740	25.597	12.6 %
NORMAL FORCE		21.482	24.001	11.7 %
FRICTION FACTOR		.347	.371	
FRICTION FORCE		7.459	8.897	19.3 %
FRICTION DIRECTION		76.	113.	37. DEG
FROM THE HORIZONTAL				

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PROJECT 1566C

NOV 20 SEGMENT NUMBER 2 FILE NAME WPOS_4C
CALIBRATION POSITION 4

TRANSDUCER	READING (N)
R-21	7.58
R-22	.40
H-21	-10.38
H-22	33.02
H-23	1.60
V-21	-5.68
V-22	6.65
V-23	23.38
V-25	-.25
T'V	5.43
T'L	2.74
NOR	32.69

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	15.41	7.98	-48.	-7.4
	Y	22.34	24.24	8.	1.9
	Z	19.21	24.10	25.	4.9

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -7.11 X PLANE
C2= 1.83 Y PLANE
C3= 3.03 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.625	1.689	.064 m
	Z=	.027	.040	.013 m
WATERPLANE ANGLE	29.		22.	-7. DEG
FLARE ANGLE	29.		32.	3. DEG
TOTAL FORCE	33.249		35.098	5.6 %
NORMAL FORCE	32.688		34.080	4.3 %
FRICTION FACTOR	.186		.246	
FRICTION FORCE	6.080		8.392	38.0 %
FRICTION DIRECTION FROM THE HORIZONTAL	63.		101.	37. DEG

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PROJECT 1566C

NOV 18 SEGMENT NUMBER 2 FILE NAME POS_5C
 CALIBRATION POSITION 5

TRANSDUCER	READING (N)
R-21	3.85
R-22	.40
H-21	3.56
H-22	19.68
H-23	2.00
V-21	-7.33
V-22	17.74
V-23	22.44
V-25	.75
T'V	12.52
T'L	-4.34
NOR	36.21

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	5.55	4.25	-24.	-1.3
	Y	24.29	25.24	4.	.9
	Z	29.42	33.61	14.	4.2

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -8.97 X PLANE
 C2= 6.29 Y PLANE
 C3= -2.46 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.759	1.792	.033 m
	Z=	.027	.036	.009 m
WATERPLANE ANGLE		23.	25.	2. DEG
FLARE ANGLE		33.	36.	3. DEG
TOTAL FORCE		38.555	42.242	9.6 %
NORMAL FORCE		36.209	39.127	8.1 %
FRICTION FACTOR		.366	.407	
FRICTION FORCE		13.246	15.920	20.2 %
FRICTION DIRECTION	109.		115.	6. DEG
FROM THE HORIZONTAL				

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 20 SEGMENT NUMBER 2 FILE NAME WPOS_SC
 CALIBRATION POSITION 5

TRANSDUCER	READING (N)
R-21	9.18
R-22	.69
H-21	-2.37
H-22	25.45
H-23	2.60
V-21	-6.78
V-22	13.68
V-23	12.34
V-25	1.50
T'V	.31
T'L	3.20
NOR	31.98

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	13.54	9.87	-27.	-3.7
Y	23.83	25.68	8.	1.8
Z	16.78	20.74	24.	4.0

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -4.89 X PLANE
 C2= 4.05 Y PLANE
 C3= .16 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.759	1.813	.054 m
	Z=	.027	.037	.010 m
WATERPLANE ANGLE	23.	26.	3.	DEG
FLARE ANGLE	33.	37.	4.	DEG

TOTAL FORCE	32.137	34.451	7.2 %
NORMAL FORCE	31.976	34.343	7.4 %
FRICTION FACTOR	.100	.079	
FRICTION FORCE	3.210	2.718	-15.3 %
FRICTION DIRECTION	6.	144.	139. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 18 SEGMENT NUMBER 2 FILE NAME POS_8C
CALIBRATION POSITION 8

TRANSDUCER	READING (N)
R-21	2.70
R-22	.40
H-21	15.82
H-22	.57
H-23	1.00
V-21	-5.13
V-22	35.11
V-23	1.31
V-25	.25
T'V	9.97
T'L	-5.48
NOR	31.81

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	3.50	3.10	-11.	-.4
	Y	17.19	17.39	1.	.2
	Z	28.87	31.55	9.	2.7

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -5.71 X PLANE
C2= 12.76 Y PLANE
C3= -6.32 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.015	2.007	-.008 m
	Z=	.027	.020	-.007 m
WATERPLANE ANGLE		30.	29.	-0. DEG
FLARE ANGLE		47.	45.	-2. DEG
TOTAL FORCE		33.779	36.153	7.0 %
NORMAL FORCE		31.807	33.240	4.5 %
FRICTION FACTOR		.358	.428	
FRICTION FORCE		11.372	14.218	25.0 %
FRICTION DIRECTION		119.	114.	-5. DEG
FROM THE HORIZONTAL				

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PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME WPOS_8C
NOV 20 CALIBRATION POSITION 8

TRANSDUCER	READING (N)
R-21	9.67
R-22	1.39
H-21	20.07
H-22	3.59
H-23	1.80
V-21	-5.86
V-22	39.64
V-23	1.50
V-25	2.25
T'V	3.42
T'L	.91
NOR	41.92

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	14.93	11.06	-26.	-3.9
Y	24.34	25.47	5.	1.1
Z	30.89	37.53	21.	6.6

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -6.37 X PLANE
C2= 14.33 Y PLANE
C3= -7.47 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		2.015	1.992	-.023 m
	Z=	.027	.033	.006 m
WATERPLANE ANGLE		30.	30.	1. DEG
FLARE ANGLE		47.	46.	-0. DEG

TOTAL FORCE	42.066	46.679	11.0 %
NORMAL FORCE	41.916	45.613	8.8 %
FRICTION FACTOR	.085	.218	
FRICTION FORCE	3.542	9.922	180.1 %
FRICTION DIRECTION	75.	109.	34. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

NOV 20 SEGMENT NUMBER 2 FILE NAME WPOS_9C
 CALIBRATION POSITION 9

TRANSDUCER	READING (N)
R-21	8.44
R-22	.79
H-21	-1.58
H-22	22.52
H-23	2.40
V-21	-.82
V-22	9.43
V-23	15.90
V-25	1.25
T'V	6.15
T'L	1.60
NOR	35.67

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	12.29	9.23	-25.	-3.1
	Y	21.95	23.33	6.	1.4
	Z	26.07	25.75	-1.	-.3

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -5.66 X PLANE
 C2= 4.11 Y PLANE
 C3= -.04 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.759	1.782	.023 m
	Z=	.072	.063	-.009 m
WATERPLANE ANGLE		26.	26.	0. DEG
FLARE ANGLE		39.	39.	-0. DEG
TOTAL FORCE		36.227	35.952	-.8 %
NORMAL FORCE		35.665	35.366	-.8 %
FRICTION FACTOR		.178	.183	
FRICTION FORCE		6.356	6.465	1.7 %
FRICTION DIRECTION FROM THE HORIZONTAL		75.	107.	32. DEG

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PROJECT 1566C

NOV 20 SEGMENT NUMBER 2 FILE NAME WPOS_10C
CALIBRATION POSITION 10

TRANSDUCER	READING (N)
R-21	8.11
R-22	.99
H-21	5.14
H-22	10.78
H-23	2.00
V-21	.18
V-22	16.08
V-23	7.67
V-25	-1.25
T'V	5.33
T'L	.91
NOR	31.70

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	11.01	9.10	-17.	-1.9
Y	17.69	17.93	1.	.2
Z	24.49	22.68	-7.	-1.8

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -4.18 X PLANE
C2= 6.10 Y PLANE
C3= -2.07 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.891	.022 m
Z=	.072	.055	-.017 m
WATERPLANE ANGLE	29.	29.	-0. DEG
FLARE ANGLE	44.	43.	-1. DEG
TOTAL FORCE	32.157	30.309	-5.7 %
NORMAL FORCE	31.699	29.923	-5.6 %
FRICTION FACTOR	.171	.161	
FRICTION FORCE	5.405	4.822	-10.8 %
FRICTION DIRECTION	80.	100.	20. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME WPOS_11C
NOV 20 CALIBRATION POSITION 11

TRANSDUCER	READING (N)
R-21	7.54
R-22	.99
H-21	11.47
H-22	2.46
H-23	.60
V-21	7.51
V-22	21.44
V-23	-.56
V-25	-2.12
T'V	12.19
T'L	.46
NOR	33.04

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	8.26	8.53	3.	.3
	Y	11.88	14.53	22.	2.6
	Z	32.12	26.26	-18.	-5.9

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.83 X PLANE
C2= 9.66 Y PLANE
C3= -3.93 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION : X=	1.979	1.991	.012 m
Z=	.072	.073	.001 m
WATERPLANE ANGLE	33.	33.	0. DEG
FLARE ANGLE	51.	51.	0. DEG
TOTAL FORCE	35.225	31.204	-11.4 %
NORMAL FORCE	33.044	30.549	-7.5 %
FRICTION FACTOR	.369	.208	
FRICTION FORCE	12.203	6.357	-47.9 %
FRICTION DIRECTION FROM THE HORIZONTAL	88.	98.	10. DEG

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PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME WPOS_11D
NOV 20 CALIBRATION POSITION 11

TRANSDUCER	READING (N)
R-21	6.47
R-22	.89
H-21	11.47
H-22	3.12
H-23	.80
V-21	2.84
V-22	18.48
V-23	.75
V-25	1.00
T'V	4.71
T'L	.46
NOR	27.74

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	9.14	7.37	-19.	-1.8
	Y	13.24	15.39	16.	2.2
	Z	23.09	23.07	-0.	-0.0

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.96 X PLANE
C2= 8.03 Y PLANE
C3= -4.15 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.979	1.969	-.010 m
	Z=	.072	.065	-.007 m
WATERPLANE ANGLE		33.	32.	-1. DEG
FLARE ANGLE		51.	49.	-1. DEG
TOTAL FORCE		28.139	28.692	2.0 %
NORMAL FORCE		27.738	28.243	1.8 %
FRICTION FACTOR		.171	.179	
FRICTION FORCE		4.736	5.059	6.8 %
FRICTION DIRECTION FROM THE HORIZONTAL		84.	113.	29. DEG

JARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2
JAN 19 1987

FILE NAME POS_88
CALIBRATION POSITION 8

TRANSDUCER	READING (N)
R-21	8.03
R-22	1.09
H-21	33.62
H-22	0.00
H-23	2.00
V-21	-14.65
V-22	62.01
V-23	.65
V-25	0.00
T*V	8.06
T*L	-9.59
NOR	58.60

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	10.34	9.12	-12.	-1.2
Y	37.48	35.62	-5.	-1.9
Z	45.60	48.01	5.	2.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -8.91 X PLANE
C2= 20.60 Y PLANE
C3= -13.04 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	2.015	2.020	.005 m
Z=	.027	0.000	-.027 m
WATERPLANE ANGLE	30.	29.	-1. DEG
FLARE ANGLE	47.	38.	-9. DEG
TOTAL FORCE	59.925	60.469	.9 %
NORMAL FORCE	58.601	56.437	-3.7 %
FRICTION FACTOR	.214	.385	
FRICTION FORCE	12.527	21.713	73.3 %
FRICTION DIRECTION	140.	116.	-24. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2
JAN 19 1987

FILE NAME POS_5B
CALIBRATION POSITION 5

TRANSDUCER	READING (N)
R-21	7.46
R-22	.59
H-21	6.92
H-22	33.49
H-23	3.80
V-21	-13.19
V-22	22.92
V-23	27.86
V-25	.75
T'V	4.15
T'L	-11.18
NDR	57.33

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	7.96	8.05	1.	.1
Y	47.60	44.21	-7.	-3.4
Z	33.16	38.34	16.	5.2

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -10.23 X PLANE
C2= 6.84 Y PLANE
C3= -4.53 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.759	1.785	.026 m
	Z=	.027	.030	.003 m
WATERPLANE ANGLE		23.	24.	1. DEG
FLARE ANGLE		33.	35.	2. DEG

TOTAL FORCE	58.554	59.074	.9 %
NORMAL FORCE	57.326	57.452	.2 %
FRICTION FACTOR	.208	.239	
FRICTION FORCE	11.929	13.746	15.2 %
FRICTION DIRECTION	160.	141.	-19. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

SEGMENT NUMBER 2
JAN 20 1987

FILE NAME POS_4D
CALIBRATION POSITION 4

TRANSDUCER	READING (N)
R-21	9.01
R-22	.59
H-21	-13.25
H-22	52.06
H-23	2.60
V-21	-10.62
V-22	12.20
V-23	49.00
V-25	0.00
T'V	10.92
T'L	-5.02
NOR	61.83

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	20.06	9.61	-52.	-10.5
	Y	46.92	51.41	10.	4.5
	Z	36.91	50.57	37.	13.7

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -14.72 X PLANE
C2= 4.04 Y PLANE
C3= 2.60 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.625	1.688	.063 m
	Z=	.027	.042	.015 m
WATERPLANE ANGLE		29.	22.	-7. DEG
FLARE ANGLE		29.	32.	3. DEG
TOTAL FORCE		62.982	72.753	15.5 %
NORMAL FORCE		61.825	69.718	12.8 %
FRICTION FACTOR		.194	.298	
FRICTION FORCE		12.015	20.794	73.1 %
FRICTION DIRECTION FROM THE HORIZONTAL		115.	119.	5. DEG

D.3 SEGMENT 3 CALIBRATION RESULTS

This appendix contains the results of external calibrations of segment 3 performed with the calibration rig. The procedure for these tests and an explanation of the calibration sheet format is given in Section 4, Volume I. The calibrations are listed in order of increasing calibration point number. The number in the file name indicates the calibration position. A file name beginning with a "W" indicates an "in-water" calibration whereas one without is an "in-air" calibration.

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_42
CALIBRATION POSITION 42

TRANSDUCER	READING (N)
R-31	.17
R-32	.19
H-31	11.12
H-32	5.35
H-33	2.55
V-31	-3.03
V-32	9.28
V-33	5.31
V-34	-3.39
V-35	1.71
V-36	1.19
T'V	6.05
T'L	-4.56
NOR	22.24

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	-1.36	.36	-126.	1.7
Y	20.83	20.02	-4.	-.8
Z	10.79	11.06	3.	.3

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -4.29 X PLANE
C2= 5.39 Y PLANE
C3= -8.78 Z PLANE

LOCATION	APPLIED	MEASURED	ERROR
:X=	1.319	1.388	.069 m
Z=	.011	.022	.011 m
WATERPLANE ANGLE	9.	11.	2. DEG
FLARE ANGLE	13.	17.	4. DEG

TOTAL FORCE	23.499	22.878	-2.6 %
NORMAL FORCE	22.244	22.051	-.9 %
FRICTION FACTOR	.341	.276	
FRICTION FORCE	7.578	6.094	-19.6 %
FRICTION DIRECTION	127.	123.	-4. DEG
FROM THE HORIZONTAL			

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_44
 CALIBRATION POSITION 44

TRANSDUCER	READING (N)
R-31	-.91
R-32	0.00
H-31	-1.44
H-32	25.22
H-33	.98
V-31	-.76
V-32	.60
V-33	7.73
V-34	-4.07
V-35	.28
V-36	1.78
T'V	8.92
T'L	-.91
NOR	29.81

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	-.52	-.91	76.	-.4
Y	28.44	24.76	-13.	-3.7
Z	12.64	5.58	-56.	-7.1

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.01 X PLANE
 C2= -.10 Y PLANE
 C3= -.14 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	.890	.880	-.010 m
Z=	.027	.099	.072 m
WATERPLANE ANGLE	1.	1.	-0. DEG
FLARE ANGLE	7.	9.	2. DEG

TOTAL FORCE	31.129	25.401	-18.4 %
NORMAL FORCE	29.810	25.331	-15.0 %
FRICTION FACTOR	.301	.074	
FRICTION FORCE	8.967	1.878	-79.1 %
FRICTION DIRECTION	96.	130.	35. DEG
FROM THE HORIZONTAL			

FRICTION DIRECTION 49.
PROJECT 1566C

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NOV 20 SEGMENT NUMBER 3 FILE NAME WPOS_44
CALIBRATION POSITION 44

TRANSDUCER	READING (N)
R-31	-.66
R-32	-.97
H-31	-2.88
H-32	32.10
H-33	1.77
V-31	-.97
V-32	1.11
V-33	8.44
V-34	-6.11
V-35	.28
V-36	1.78
T'V	3.16
T'L	2.74
NOR	35.20

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	3.22	-1.63	-151.	-4.9
	Y	34.47	30.99	-10.	-3.5
	Z	7.61	4.53	-40.	-3.1

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -1.91 X PLANE
C2= -.22 Y PLANE
C3= .29 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		.890	.880	-.010 m
	Z=	.027	.083	.056 m
WATERPLANE ANGLE		1.	1.	-0. DEG
FLARE ANGLE		7.	9.	1. DEG

TOTAL FORCE	35.448	31.360	-11.5 %
NORMAL FORCE	35.200	31.299	-11.1 %
FRICTION FACTOR	.119	.063	
FRICTION FORCE	4.182	1.963	-53.1 %
FRICTION DIRECTION	49.	-176.	-225. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 17 SEGMENT NUMBER 3 FILE NAME POS_45
CALIBRATION POSITION 45

TRANSDUCER	READING (N)
R-31	4.39
R-32	.58
H-31	12.56
H-32	8.64
H-33	2.46
V-31	-4.22
V-32	12.81
V-33	7.15
V-34	-3.62
V-35	2.56
V-36	2.37
T'V	10.91
T'L	-2.74
NOR	28.67

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	1.28	4.97	287.	3.7
	Y	25.33	23.66	-7.	-1.7
	Z	17.48	17.05	-2.	-.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -6.43 X PLANE
C2= 7.54 Y PLANE
C3= -8.36 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.319	1.354	.035 m
Z=	.027	.039	.012 m
WATERPLANE ANGLE	9.	10.	1. DEG
FLARE ANGLE	14.	17.	2. DEG

TOTAL FORCE	30.799	29.582	-4.0 %
NORMAL FORCE	28.672	27.981	-2.4 %
FRICTION FACTOR	.392	.343	
FRICTION FORCE	11.247	9.600	-14.6 %
FRICTION DIRECTION FROM THE HORIZONTAL	104.	86.	-18. DEG

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PROJECT 1566C

SEGMENT NUMBER 3 FILE NAME WPOS_45A
NOV 20 CALIBRATION POSITION 45

TRANSDUCER	READING (N)
R-31	6.12
R-32	2.13
H-31	13.80
H-32	10.94
H-33	7.76
V-31	-4.32
V-32	11.14
V-33	6.25
V-34	-4.98
V-35	.85
V-36	1.78
T'V	6.65
T'L	2.28
NOR	36.47

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	7.60	8.25	9.	.7
Y	33.01	32.49	-2.	-.5
Z	15.22	10.72	-30.	-4.5

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -4.28 X PLANE
C2= 4.66 Y PLANE
C3= -10.28 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.319	1.343	.024 m
Z=	.027	.011	-.016 m
WATERPLANE ANGLE	9.	9.	0. DEG
FLARE ANGLE	14.	14.	-0. DEG
TOTAL FORCE	37.138	35.197	-5.2 %
NORMAL FORCE	36.466	34.988	-4.1 %
FRICTION FACTOR	.193	.109	
FRICTION FORCE	7.034	3.828	-45.6 %
FRICTION DIRECTION	71.	42.	-29. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

NOV 20 SEGMENT NUMBER 3 FILE NAME WPOS_46
CALIBRATION POSITION 46

TRANSDUCER	READING (N)
R-31	9.19
R-32	1.55
H-31	22.65
H-32	.18
H-33	2.36
V-31	-5.84
V-32	21.68
V-33	.94
V-34	-1.70
V-35	.85
V-36	.59
T'V	4.56
T'L	3.65
NOR	34.44

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	12.67	10.74	-15.	-1.9
	Y	26.52	25.18	-5.	-1.3
	Z	18.89	16.53	-13.	-2.4

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -5.89 X PLANE
C2= 11.35 Y PLANE
C3= -13.48 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.613	1.594	-.019 m
Z=	.027	.011	-.016 m
WATERPLANE ANGLE	18.	17.	-2. DEG
FLARE ANGLE	27.	24.	-3. DEG
TOTAL FORCE	34.935	31.979	-8.5 %
NORMAL FORCE	34.444	31.499	-8.5 %
FRICTION FACTOR	.170	.175	
FRICTION FORCE	5.838	5.518	-5.5 %
FRICTION DIRECTION FROM THE HORIZONTAL	51.	56.	4. DEG

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PROJECT 1566C

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_47
CALIBRATION POSITION 47

TRANSDUCER	READING (N)
R-31	-1.61
R-32	-.19
H-31	-1.24
H-32	25.84
H-33	.98
V-31	-.65
V-32	.30
V-33	10.70
V-34	-3.32
V-35	.28
V-36	1.48
T'V	10.77
T'L	-2.28
NOR	31.43

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	-1.92	-1.81	-6.	.1
	Y	29.81	25.59	-14.	-4.2
	Z	14.73	8.81	-40.	-5.9

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -3.11 X PLANE
C2= -.02 Y PLANE
C3= -.57 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	.890	.889	-.001 m
Z=	.042	.042	0.000 m
WATERPLANE ANGLE	1.	1.	-0. DEG
FLARE ANGLE	7.	8.	0. DEG
TOTAL FORCE	33.303	27.122	-18.6 %
NORMAL FORCE	31.432	26.498	-15.7 %
FRICTION FACTOR	.350	.218	
FRICTION FORCE	11.008	5.782	-47.5 %
FRICTION DIRECTION FROM THE HORIZONTAL	102.	111.	9. DEG

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PROJECT 1566C

NOV 20 SEGMENT NUMBER 3 FILE NAME WPOS_47
CALIBRATION POSITION 47

TRANSDUCER	READING (N)
R-31	-.54
R-32	-.68
H-31	-1.65
H-32	28.93
H-33	1.77
V-31	-.65
V-32	.81
V-33	9.30
V-34	-4.30
V-35	.28
V-36	1.78
T'V	4.61
T'L	2.74
NOP	30.89

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	3.11	-1.22	-139.	-4.3
	Y	30.01	29.05	-3.	-1.0
	Z	8.56	7.22	-16.	-1.3

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.42 X PLANE
C2= .11 Y PLANE
C3= -.40 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		.890	.909	.019 m
	Z=	.042	.035	-.007 m
WATERPLANE ANGLE		1.	1.	0. DEG
FLARE ANGLE		7.	8.	0. DEG

TOTAL FORCE	31.356	29.958	-4.5 %
NORMAL FORCE	30.893	29.730	-3.8 %
FRICTION FACTOR	.174	.124	
FRICTION FORCE	5.366	3.690	-31.2 %
FRICTION DIRECTION	59.	119.	60. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_48
 CALIBRATION POSITION 48

TRANSDUCER	READING (N)
R-31	5.05
R-32	.58
H-31	18.94
H-32	11.99
H-33	4.71
V-31	-4.49
V-32	17.29
V-33	9.14
V-34	-4.60
V-35	3.41
V-36	2.97
T'V	12.90
T'L	-4.56
NOR	44.11

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	2.18	5.63	158.	3.5
Y	39.43	35.65	-10.	-3.8
Z	23.95	23.72	-1.	-.2

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -8.14 X PLANE
 C2= 10.93 Y PLANE
 C3= -13.52 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.319	1.373	.054 m
Z=	.042	.053	.011 m
WATERPLANE ANGLE	10.	12.	2. DEG
FLARE ANGLE	15.	19.	3. DEG
TOTAL FORCE	46.185	43.193	-6.5 %
NORMAL FORCE	44.111	41.700	-5.5 %
FRICTION FACTOR	.310	.270	
FRICTION FORCE	13.683	11.260	-17.7 %
FRICTION DIRECTION	109.	98.	-11. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

NOV 20 SEGMENT NUMBER 3 FILE NAME WPOS_48A
CALIBRATION POSITION 48

TRANSDUCER	READING (N)
R-31	5.88
R-32	1.94
H-31	13.28
H-32	10.32
H-33	7.66
V-31	-3.57
V-32	9.28
V-33	5.35
V-34	-3.88
V-35	.85
V-36	1.19
T'V	4.08
T'L	2.28
NOR	36.01

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	7.99	7.81	-2.	-.2
	Y	32.82	31.26	-5.	-1.6
	Z	13.32	9.22	-31.	-4.1

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1=	-3.24	X PLANE		
C2=	3.90	Y PLANE		
C3=	-9.99	Z PLANE		
LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.319	1.345	.026 m
	Z=	.042	.025	-.017 m
WATERPLANE ANGLE		10.	10.	-0. DEG
FLARE ANGLE		15.	15.	-0. DEG
TOTAL FORCE		36.314	33.515	-7.7 %
NORMAL FORCE		36.011	33.417	-7.2 %
FRICTION FACTOR		.130	.077	
FRICTION FORCE		4.678	2.560	-45.3 %
FRICTION DIRECTION FROM THE HORIZONTAL		61.	17.	-44. DEG

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PROJECT 1566C

SEGMENT NUMBER 3 FILE NAME POS_49
NOV 18 CALIBRATION POSITION 49

TRANSDUCER	READING (N)
R-31	8.61
R-32	.58
H-31	27.59
H-32	-.62
H-33	1.57
V-31	-5.41
V-32	24.20
V-33	.55
V-34	-1.28
V-35	1.42
V-36	.59
T'V	5.81
T'L	-.91
NOR	36.45

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	8.89	9.19	3.	.3
	Y	28.46	28.55	0.	.1
	Z	21.78	20.07	-8.	-1.7

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1=	-6.43	X PLANE
C2=	13.89	Y PLANE
C3=	-17.06	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.613	1.607	-.006 m
	Z= .042	.034	-.008 m
WATERPLANE ANGLE	19.	19.	-1. DEG
FLARE ANGLE	28.	27.	-1. DEG
TOTAL FORCE	36.918	36.086	-2.3 %
NORMAL FORCE	36.446	35.752	-1.9 %
FRICTION FACTOR	.161	.137	
FRICTION FORCE	5.882	4.902	-16.7 %
FRICTION DIRECTION FROM THE HORIZONTAL	99.	94.	-5. DEG

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PROJECT 1566C

SEGMENT NUMBER 3 FILE NAME WPOS_49
NOV 20 CALIBRATION POSITION 49

TRANSDUCER	READING (N)
R-31	5.21
R-32	.97
H-31	16.37
H-32	-.18
H-33	1.77
V-31	-2.92
V-32	14.02
V-33	.59
V-34	-.83
V-35	.57
V-36	0.00
T'V	3.18
T'L	0.00
NOR	22.97

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	6.22	6.18	-1.	-0.0
Y	17.95	17.96	0.	0.0
Z	13.29	11.42	-14.	-1.9

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -3.61 X PLANE
C2= 7.87 Y PLANE
C3= -10.25 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.613	1.607	-.006 m
Z=	.042	.034	-.008 m
WATERPLANE ANGLE	19.	19.	-1. DEG
FLARE ANGLE	28.	27.	-1. DEG
TOTAL FORCE	23.185	22.165	-4.4 %
NORMAL FORCE	22.966	22.079	-3.9 %
FRICTION FACTOR	.138	.088	
FRICTION FORCE	3.177	1.947	-38.7 %
FRICTION DIRECTION	0.	85.	85. DEG
FROM THE HORIZONTAL			

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PROJECT 1566C

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_50
CALIBRATION POSITION 50

TRANSDUCER	READING (N)
R-31	0.00
R-32	-.39
H-31	-1.85
H-32	32.28
H-33	.98
V-31	-.54
V-32	.20
V-33	11.33
V-34	-2.34
V-35	0.00
V-36	1.19
T'V	7.17
T'L	-.91
NOR	35.29

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	-.44	-.39	-12.	.1
	Y	33.94	31.41	-7.	-2.5
	Z	12.07	9.84	-18.	-2.2

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -2.81 X PLANE
C2= -.15 Y PLANE
C3= .21 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	.890	.882	-.008 m
Z=	.072	.059	-.013 m
WATERPLANE ANGLE	1.	1.	-0. DEG
FLARE ANGLE	8.	8.	-0. DEG
TOTAL FORCE	36.026	32.916	-8.6 %
NORMAL FORCE	35.294	32.443	-8.1 %
FRICTION FACTOR	.205	.171	
FRICTION FORCE	7.223	5.557	-23.1 %
FRICTION DIRECTION FROM THE HORIZONTAL	97.	97.	-0. DEG

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_50A
CALIBRATION POSITION 50

TRANSDUCER	READING (N)
R-31	-.41
R-32	-.19
H-31	-1.44
H-32	29.19
H-33	.79
V-31	-.22
V-32	0.00
V-33	9.06
V-34	-1.06
V-35	0.00
V-36	.59
T'V	6.93
T'L	-.68
NOR	30.95

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	-.27	-.61	125.	-.3
Y	29.67	28.54	-4.	-1.1
Z	11.22	8.38	-25.	-2.8

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -1.86 X PLANE
C2= .01 Y PLANE
C3= -.04 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		.890	.895	.005 m
	Z=	.072	.073	.001 m
WATERPLANE ANGLE	1.	1.	0.	DEG
FLARE ANGLE	8.	9.	0.	DEG

TOTAL FORCE	31.722	29.750	-6.2 %
NORMAL FORCE	30.947	29.453	-4.8 %
FRICTION FACTOR	.225	.142	
FRICTION FORCE	6.967	4.193	-39.8 %
FRICTION DIRECTION	96.	105.	9. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 18 SEGMENT NUMBER 3 FILE NAME POS_51
 CALIBRATION POSITION 51

TRANSDUCER	READING (N)
R-31	7.86
R-32	.77
H-31	15.03
H-32	10.76
H-33	4.32
V-31	-2.49
V-32	13.31
V-33	7.27
V-34	-2.49
V-35	2.84
V-36	2.37
T'V	11.62
T'L	-.46
NOR	37.77

RESOLVED	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
FORCES IN X	5.79	8.64	49.	2.8
Y	31.89	30.11	-6.	-1.8
Z	22.61	20.82	-8.	-1.8

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -6.29 X PLANE
 C2= 8.98 Y PLANE
 C3= -9.66 Z PLANE

LOCATION	APPLIED	MEASURED	ERROR
:X=	1.319	1.364	.045 m
Z=	.072	.078	.006 m
WATERPLANE ANGLE	11.	12.	1. DEG
FLARE ANGLE	18.	21.	3. DEG

TOTAL FORCE	39.517	37.612	-4.8 %
NORMAL FORCE	37.766	36.555	-3.2 %
FRICTION FACTOR	.308	.242	
FRICTION FORCE	11.632	8.856	-23.9 %
FRICTION DIRECTION	92.	77.	-15. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 17 SEGMENT NUMBER 3 FILE NAME POS_52
 CALIBRATION POSITION 52

TRANSDUCER	READING (N)
R-31	6.33
R-32	.58
H-31	13.59
H-32	.09
H-33	.59
V-31	-3.35
V-32	21.28
V-33	.04
V-34	-.83
V-35	1.71
V-36	.59
T*V	10.77
T*L	.91
NOR	23.14

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	6.03	6.91	15.	.9
	Y	13.31	14.27	7.	1.0
	Z	20.95	19.43	-7.	-1.5

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -6.48 X PLANE
 C2= 13.43 Y PLANE
 C3= -7.61 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.613	1.606	-.007 m
	Z=	.072	.042	-.030 m
WATERPLANE ANGLE		21.	19.	-2. DEG
FLARE ANGLE		32.	28.	-4. DEG
TOTAL FORCE		25.541	25.079	-1.8 %
NORMAL FORCE		23.143	22.814	-1.4 %
FRICTION FACTOR		.467	.457	
FRICTION FORCE		10.805	10.416	-3.6 %
FRICTION DIRECTION		85.	79.	-6. DEG
FROM THE HORIZONTAL				

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 3 FILE NAME POS_54
 NOV 18 CALIBRATION POSITION 54

TRANSDUCER	READING (N)
R-31	6.87
R-32	.58
H-31	14.00
H-32	9.35
H-33	3.93
V-31	1.08
V-32	9.13
V-33	5.35
V-34	.68
V-35	2.56
V-36	2.37
T'V	8.64
T'L	-2.28
NOR	35.33

RESOLVED FORCES IN	X	APPLIED	MEASURED	% DIFFERENCE	ERROR (N)
	X	4.70	7.45	58.	2.7
	Y	28.50	27.28	-4.	-1.2
	Z	22.21	21.17	-5.	-1.0

MOMENTS ABOUT SHIP AT 24.75 FT WATERLINE

C1= -4.45 X PLANE
 C2= 8.60 Y PLANE
 C3= -9.13 Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.319	1.356	.037 m
	Z=	.133	.140	.007 m
WATERPLANE ANGLE		14.	15.	1. DEG
FLARE ANGLE		25.	27.	2. DEG
TOTAL FORCE		36.442	35.323	-3.1 %
NORMAL FORCE		35.329	34.707	-1.8 %
FRICTION FACTOR		.253	.189	
FRICTION FORCE		8.937	6.567	-26.5 %
FRICTION DIRECTION	105.		90.	-14. DEG
FROM THE HORIZONTAL				

D.4 RESULT SHEETS OF CALIBRATION RIG VERIFICATION TESTS

This appendix contains the results of the calibration rig verification test. The procedure for these tests and an explanation of the calibration sheet format is given in Section 4, Volume I. The calibrations are listed in order of increasing angle α and within each value of α by increasing angle θ . The format of the file name is C α - θ where C can be C, D or E and only serves to differentiate between different tests at the same angles.

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL

FILE NAME CO_71

JAN 6 1987

TRANSDUCER	READING (N)	
LONG	-1.29	-1.29
HOR	50.78	50.78
VER	45.38	45.04
T'V	26.25	26.25
T'L	-4.56	-4.56
NOR	63.76	63.76

ALPHA	0.	THETA	71.			
		APPLIED	MEASURED	RATIO	DIFF (N)	
FORCES IN X		-4.56	-1.29	.28	3.3	
	Y	51.74	50.78	.98	-1.0	
	Z	45.58	45.38	1.00	-.2	
	TOT	69.11	68.12	.99	-1.0	
APPLIED FRICTION RATIO			.42			
FORCES IN X		-4.56	-1.29	.28	3.3	
	Y	51.74	50.78	.98	-1.0	
	Z	45.58	45.04	.99	-.5	
	TOT	69.11	67.89	.98	-1.2	
APPLIED FRICTION RATIO			.42			

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME D0_71

TRANSDUCER	READING (N)	
LONG	-.32	-.32
HOR	20.59	40.83
VER	15.81	32.66
T'V	8.90	18.60
T'L	-1.83	-2.74
NOR	25.47	50.56

ALPHA 0. THETA 71.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	-1.83	-.32	.18	1.5
Y	21.18	20.59	.97	-.6
Z	16.71	15.81	.95	-.9
TOT	27.04	25.96	.96	-1.1
APPLIED FRICTION RATIO		.36		

FORCES IN X	-2.74	-.32	.12	2.4
Y	41.75	40.83	.98	-.9
Z	34.05	32.66	.96	-1.4
TOT	53.94	52.29	.97	-1.7
APPLIED FRICTION RATIO		.37		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL

FILE NAME C5_71

JAN 6 1987

TRANSDUCER	READING (N)	
LONG	.32	.97
HOR	31.22	48.72
VER	29.57	48.13
T'V	18.53	29.89
T'L	-5.02	-6.39
NOR	39.51	62.27

ALPHA 5. THETA 71.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	-2.27	.32	-.14	2.6
Y	31.64	31.22	.99	-.4
Z	30.38	29.57	.97	-.8
TOT	43.92	43.00	.98	-.9
APPLIED FRICTION RATIO		.49		

FORCES IN X	-2.08	.97	-.46	3.0
Y	49.52	48.72	.98	-.8
Z	48.53	48.13	.99	-.4
TOT	69.37	68.49	.99	-.9
APPLIED FRICTION RATIO		.49		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C9_71

TRANSDUCER	READING (N)	
LONG	3.22	6.92
HOR	21.62	39.29
VER	23.03	37.13
T'V	15.55	22.82
T'L	-1.37	-1.83
NOR	28.78	50.66

ALPHA 9. THETA 71.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	2.11	3.22	1.52	1.1
Y	22.09	21.62	.98	-.5
Z	24.07	23.03	.96	-1.0
TOT	32.74	31.75	.97	-1.0
APPLIED FRICTION RATIO		.54		

FORCES IN X	4.53	6.92	1.53	2.4
Y	40.26	39.29	.98	-1.0
Z	38.07	37.13	.98	-.9
TOT	55.59	54.50	.98	-1.1
APPLIED FRICTION RATIO		.45		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C15_50

TRANSDUCER	READING (N)	
LONG	2.90	3.54
HOR	14.41	19.04
VER	13.41	16.50
T'V	2.07	2.30
T'L	-1.83	-2.51
NOR	20.37	24.72

ALPHA	15.	THETA	50.			
		APPLIED	MEASURED	RATIO	DIFF (N)	
FORCES IN X		1.93	2.90	1.50	1.0	
	Y	14.26	14.41	1.01	.1	
	Z	14.68	13.41	.91	-1.3	
	TOT	20.56	19.90	.97	-.7	
APPLIED FRICTION RATIO			.14			
FORCES IN X		2.09	3.54	1.69	1.4	
	Y	17.51	19.04	1.09	1.5	
	Z	17.66	16.50	.93	-1.2	
	TOT	24.96	25.45	1.02	.5	
APPLIED FRICTION RATIO			.14			

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME D15_50

TRANSDUCER	READING (N)	
LONG	3.54	6.44
HOR	12.70	26.76
VER	11.35	19.94
T'V	.97	-.65
T'L	-.91	-2.74
NOR	17.78	34.91

ALPHA 15. THETA 50.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	2.48	3.54	1.43	1.1
Y	12.79	12.70	.99	-.1
Z	12.17	11.35	.93	-.8
TOT	17.83	17.39	.98	-.4
APPLIED FRICTION RATIO		.07		
FORCES IN X	4.39	6.44	1.47	2.1
Y	26.95	26.76	.99	-.2
Z	21.94	19.94	.91	-2.0
TOT	35.03	33.99	.97	-1.0
APPLIED FRICTION RATIO		.08		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C15_56

TRANSDUCER	READING (N)	
LONG	3.22	5.96
HOR	14.41	25.39
VER	17.19	23.03
T'V	7.39	6.57
T'L	-1.83	-2.74
NOR	23.06	35.68

ALPHA	15.	THETA	56.		
RESOLVED		APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	2.12		3.22	1.52	1.1
	Y 14.95		14.41	.96	-.5
	Z 19.03		17.19	.90	-1.8
	TOT 24.29		22.66	.93	-1.6
APPLIED FRICTION RATIO			.33		
FORCES IN X	4.06		5.96	1.47	1.9
	Y 25.73		25.39	.99	-.3
	Z 25.40		23.03	.91	-2.4
	TOT 36.38		34.80	.96	-1.6
APPLIED FRICTION RATIO			.20		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C15_60

TRANSDUCER	READING (N)	
LONG	3.86	9.98
HOR	15.27	39.80
VER	18.57	34.04
T'V	9.58	11.38
T'L	-1.60	-3.65
NOR	23.91	53.94

ALPHA	15.	THETA	60.			
RESOLVED		APPLIED		MEASURED	RATIO	DIFF (N)
FORCES IN X		2.57		3.86	1.50	1.3
	Y	15.78		15.27	.97	-.5
	Z	20.25		18.57	.92	-1.7
	TOT	25.80		24.35	.94	-1.5
APPLIED FRICTION RATIO				.41		

FORCES IN X		7.09		9.98	1.41	2.9
	Y	40.58		39.80	.98	-.8
	Z	36.82		34.04	.92	-2.8
	TOT	55.25		53.31	.96	-1.9
APPLIED FRICTION RATIO				.22		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME D15_61

TRANSDUCER	READING (N)	
LONG	4.51	6.12
HOR	22.30	31.22
VER	26.82	32.32
T'V	13.54	14.63
T'L	-2.74	-4.11
NOR	33.86	44.55

ALPHA	15.	THETA	61.		
	APPLIED		MEASURED	RATIO	DIFF (N)
FORCES IN X	3.32		4.51	1.36	1.2
Y	22.98		22.30	.97	-.7
Z	28.26		26.82	.95	-1.4
TOT	36.57		35.17	.96	-1.4
APPLIED FRICTION RATIO			.41		

FORCES IN X	4.28	6.12	1.43	1.8
Y	31.85	31.22	.98	-.6
Z	34.39	32.32	.94	-2.1
TOT	47.07	45.35	.96	-1.7
APPLIED FRICTION RATIO		.34		

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C15

TRANSDUCER	READING (N)	
LONG	5.47	8.69
HOR	23.33	37.06
VER	26.64	36.27
T'U	15.21	18.18
T'L	-2.51	-3.88
NOR	33.71	50.55

ALPHA	15.	THETA	66.			
RESOLVED		APPLIED		MEASURED	RATIO	DIFF (N)
FORCES IN X	3.94			5.47	1.39	1.5
	Y 24.42			23.33	.96	-1.1
	Z 27.60			26.64	.97	-1.0
	TOT 37.06			35.84	.97	-1.2
APPLIED FRICTION RATIO				.46		
FORCES IN X	6.29			8.69	1.38	2.4
	Y 38.47			37.06	.96	-1.4
	Z 37.17			36.27	.98	-.9
	TOT 53.86			52.58	.98	-1.3
APPLIED FRICTION RATIO				.37		

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PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C15_71

TRANSDUCER	READING (N)	
LONG	6.44	9.98
HOR	24.02	38.77
VER	20.28	30.25
T'V	12.41	16.71
T'L	-1.83	-3.20
NOR	31.08	48.54

ALPHA 15. THETA 71.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	4.79	6.44	1.34	1.6
Y	24.95	24.02	.96	-.9
Z	21.86	20.28	.93	-1.6
TOT	33.51	32.09	.96	-1.4
APPLIED FRICTION RATIO		.40		

FORCES IN X	7.38	9.98	1.35	2.6
Y	39.90	38.77	.97	-1.1
Z	31.61	30.25	.96	-1.4
TOT	51.44	50.18	.98	-1.3
APPLIED FRICTION RATIO		.35		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C15_81

TRANSDUCER	READING (N)	
LONG	8.05	11.59
HOR	29.51	43.58
VER	12.38	24.41
T'V	8.61	17.85
T'L	-1.83	-3.20
NOR	32.96	49.36

ALPHA	15.	THETA	81.			
		APPLIED	MEASURED	RATIO	DIFF (N)	
FORCES IN X		6.31	8.05	1.27	1.7	
	Y	30.62	29.51	.96	-1.1	
	Z	13.66	12.38	.91	-1.3	
	TOT	34.12	33.00	.97	-1.1	
APPLIED FRICTION RATIO			.27			
FORCES IN X		8.81	11.59	1.32	2.8	
	Y	45.22	43.58	.96	-1.6	
	Z	25.35	24.41	.96	-.9	
	TOT	52.58	51.27	.98	-1.3	
APPLIED FRICTION RATIO			.37			

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C20_60

TRANSDUCER	READING (N)	
LONG	4.83	5.80
HOR	17.16	20.24
VER	23.38	33.00
T'V	12.94	20.11
T'L	-2.74	-3.65
NOR	27.93	36.39

ALPHA	20.	THETA	60.		
		APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X		3.49	4.83	1.39	1.3
	Y	17.59	17.16	.98	-.4
	Z	25.17	23.38	.93	-1.8
	TOT	30.90	29.40	.95	-1.5
APPLIED FRICTION RATIO			.47		

FORCES IN X	3.91	5.80	1.48	1.9	
	Y	21.41	20.24	.95	-1.2
	Z	35.60	33.00	.93	-2.6

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PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C20_71

TRANSDUCER	READING (N)	
LONG	6.44	10.95
HOR	21.96	36.03
VER	15.81	29.22
T'V	7.86	15.63
T'L	-2.74	-4.56
NOR	27.61	46.15

ALPHA	20.	THETA	71.			
		APPLIED	MEASURED	RATIO	DIFF (N)	
FORCES IN X		5.48	6.44	1.17	1.0	
	Y	23.07	21.96	.95	-1.1	
	Z	16.42	15.81	.96	-.6	
	TOT	28.84	27.82	.96	-1.0	
APPLIED FRICTION RATIO			.30			
FORCES IN X		8.89	10.95	1.23	2.1	
	Y	37.78	36.03	.95	-1.8	
	Z	29.80	29.22	.98	-.6	
	TOT	48.94	47.66	.97	-1.3	
APPLIED FRICTION RATIO			.35			

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C24_60

TRANSDUCER	READING (N)	
LONG	8.53	11.59
HOR	27.11	37.06
VER	21.83	26.99
T'V	6.19	6.09
T'L	-5.02	-6.85
NOR	36.06	47.50

ALPHA	24.	THETA	60.			
		APPLIED	MEASURED	RATIO	DIFF (N)	
FORCES IN X	6.86		8.53	1.24	1.7	
Y	27.74		27.11	.98	-.6	
Z	23.39		21.83	.93	-1.6	
TOT	36.93		35.83	.97	-1.1	
APPLIED FRICTION RATIO			.22			
FORCES IN X	9.24		11.59	1.25	2.4	
Y	37.58		37.06	.99	-.5	
Z	29.03		26.99	.93	-2.0	
TOT	48.38		47.29	.98	-1.1	
APPLIED FRICTION RATIO			.19			

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C25_53

TRANSDUCER	READING (N)	
LONG	3.22	5.47
HOR	10.98	20.24
VER	20.28	34.21
T'V	10.69	16.55
T'L	-2.74	-5.48
NOR	22.35	38.67

ALPHA 25. THETA 53.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	2.34	3.22	1.37	.9
Y	11.51	10.98	.95	-.5
Z	21.99	20.28	.92	-1.7
TOT	24.93	23.29	.93	-1.6
APPLIED FRICTION RATIO		.49		

FORCES IN X	3.88	5.47	1.41	1.6
Y	21.28	20.24	.95	-1.0
Z	36.49	34.21	.94	-2.3
TOT	42.42	40.12	.95	-2.3
APPLIED FRICTION RATIO		.45		

CALIBRATION RIG CAL

FILE NAME C25_56

JAN 7 1987

TRANSDUCER READING (N)

LONG	4.83	5.80
HOR	14.07	16.13
VER	12.03	11.35
T'V	2.35	.83
T'L	-2.28	-2.74
NOR	19.00	20.54

ALPHA 25. THETA 56.

RESOLVED APPLIED

FORCES IN X 4.03

Y 14.05

Z 12.58

TOT 19.28

APPLIED FRICTION RATIO

MEASURED

4.83

14.07

12.03

19.13

.17

RATIO

1.20

1.00

.96

.99

DIFF (N)

.8

0.0

-.5

-.1

FORCES IN X 4.52

Y 16.17

Z 12.17

TOT 20.74

APPLIED FRICTION RATIO

5.80

16.13

11.35

20.55

.14

1.28

1.00

.93

.99

1.3

-0.0

-.8

-.2

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME D25_60

TRANSDUCER	READING (N)	
LONG	3.22	7.41
HOR	7.55	20.42
VER	9.97	23.03
T'V	5.04	10.10
T'L	-.91	-3.65
NOR	12.35	31.02

ALPHA	25.	THETA	60.		
		APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X		2.63	3.22	1.22	.6
	Y	7.80	7.55	.97	-.2
	Z	10.54	9.97	.95	-.6
	TOT	13.37	12.91	.97	-.5
APPLIED FRICTION RATIO			.41		
FORCES IN X		5.91	7.41	1.25	1.5
	Y	21.32	20.42	.96	-.9
	Z	24.25	23.03	.95	-1.2
	TOT	32.83	31.66	.96	-1.2
APPLIED FRICTION RATIO			.35		

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PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C25_67

TRANSDUCER	READING (N)	
LONG	8.37	10.95
HOR	19.56	28.99
VER	14.78	29.22
T'V	6.03	15.11
T'L	-1.83	-4.56
NOR	26.19	41.01

ALPHA 25. THETA 67.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	7.54	8.37	1.11	.8
Y	20.49	19.56	.95	-.9
Z	15.78	14.78	.94	-1.0
TOT	26.94	25.91	.96	-1.0
APPLIED FRICTION RATIO		.24		

FORCES IN X	9.32	10.95	1.17	1.6
Y	30.79	28.99	.94	-1.8
Z	29.93	29.22	.98	-.7
TOT	43.94	42.60	.97	-1.3
APPLIED FRICTION RATIO		.38		

JARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME E25_71

TRANSDUCER	READING (N)	
LONG	8.69	14.49
HOR	24.02	39.12
VER	15.99	25.44
T'V	7.66	11.66
T'L	-4.11	-6.39
NOR	29.78	48.42

ALPHA	25.	THETA	71.		
		APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X		7.12	8.69	1.22	1.6
	Y	25.00	24.02	.96	-1.0
	Z	16.93	15.99	.94	-.9
	TOT	31.02	30.13	.97	-.9
APPLIED FRICTION RATIO			.29		
FORCES IN X		11.95	14.49	1.21	2.5
	Y	40.76	39.12	.96	-1.6
	Z	26.79	25.44	.95	-1.3
	TOT	50.22	48.86	.97	-1.4
APPLIED FRICTION RATIO			.27		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C26_55

TRANSDUCER	READING (N)					
LONG	.97	2.25	4.51	3.22	1.29	.32
HOR	2.74	6.52	12.18	8.92	5.15	2.40
VER	3.27	9.11	19.42	12.89	7.74	2.23
T'V	1.29	4.54	9.46	5.83	3.63	.32
T'L	-.46	-1.37	-2.28	-1.83	-1.37	-.91
NOR	4.37	11.55	22.72	15.92	8.77	3.17

ALPHA	26.	THETA	55.			
	APPLIED		MEASURED	RATIO	DIFF (N)	
FORCES IN X	.84		.97	1.16	.1	
Y	2.76		2.74	1.00	-0.0	
Z	3.56		3.27	.92	-.3	
TOT	4.58		4.37	.96	-.2	
APPLIED FRICTION RATIO			.31			
FORCES IN X	1.78		2.25	1.27	.5	
Y	6.77		6.52	.96	-.2	
Z	10.34		9.11	.88	-1.2	
TOT	12.49		11.43	.92	-1.1	
APPLIED FRICTION RATIO			.41			
FORCES IN X	3.73		4.51	1.21	.8	
Y	12.85		12.18	.95	-.7	
Z	20.78		19.42	.93	-1.4	
TOT	24.72		23.37	.95	-1.3	
APPLIED FRICTION RATIO			.43			
FORCES IN X	2.61		3.22	1.23	.6	
Y	9.52		8.92	.94	-.6	
Z	13.91		12.89	.93	-1.0	
TOT	17.05		16.01	.94	-1.0	
APPLIED FRICTION RATIO			.38			
FORCES IN X	1.01		1.29	1.28	.3	
Y	5.19		5.15	.99	-0.0	
Z	8.00		7.74	.97	-.3	
TOT	9.59		9.38	.98	-.2	
APPLIED FRICTION RATIO			.44			
FORCES IN X	.23		.32	1.37	.1	
Y	2.56		2.40	.94	-.2	
Z	2.08		2.23	1.07	.2	
TOT	3.31		3.30	1.00	-0.0	
APPLIED FRICTION RATIO			.31			

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME C30_61

TRANSDUCER	READING (N)	
LONG	6.44	16.74
HOR	14.07	35.00
VER	17.53	26.13
T'V	8.62	5.67
T'L	-2.74	-5.93
NOR	22.70	47.49

ALPHA	30.	THETA	61.		
		APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X		5.47	6.44	1.18	1.0
	Y	14.94	14.07	.94	-.9
	Z	18.54	17.53	.95	-1.0
	TOT	24.43	23.38	.96	-1.0
APPLIED FRICTION RATIO			.40		
FORCES IN X		14.26	16.74	1.17	2.5
	Y	36.56	35.00	.96	-1.6
	Z	27.99	26.13	.93	-1.9
	TOT	48.20	46.77	.97	-1.4
APPLIED FRICTION RATIO			.17		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL

FILE NAME C35_61

JAN 7 1987

TRANSDUCER	READING (N)	
LONG	7.08	10.95
HOR	11.67	19.21
VER	14.78	17.53
T'V	6.65	5.43
T'L	-1.83	-3.65
NOR	19.89	28.54

ALPHA 35. THETA 61.

	APPLIED	MEASURED	RATIO	DIFF (N)
FORCES IN X	6.63	7.08	1.07	.5
Y	12.66	11.67	.92	-1.0
Z	15.46	14.78	.96	-.7
TOT	21.05	20.12	.96	-.9
APPLIED FRICTION RATIO		.35		

FORCES IN X	9.82	10.95	1.11	1.1
Y	20.39	19.21	.94	-1.2
Z	18.59	17.53	.94	-1.1
TOT	29.28	28.22	.96	-1.1
APPLIED FRICTION RATIO		.23		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 6 1987

FILE NAME C35_71

TRANSDUCER	READING (N)	
LONG	12.56	6.76
HOR	23.33	11.32
VER	8.25	4.81
T'V	-5.56	.18
T'L	-4.56	-1.60
NOR	27.61	14.21

ALPHA	35.	THETA	71.		
	APPLIED		MEASURED	RATIO	DIFF (N)
FORCES IN X	11.34		12.56	1.11	1.2
Y	24.15		23.33	.97	-.8
Z	8.47		8.25	.97	-.2
TOT	28.00		27.75	.99	-.2
APPLIED FRICTION RATIO			.17		

FORCES IN X	6.36		6.76	1.06	.4
Y	11.88		11.32	.95	-.6
Z	4.80		4.81	1.00	0.0
TOT	14.30		14.04	.98	-.3
APPLIED FRICTION RATIO			.11		

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL
JAN 7 1987

FILE NAME HYS2_23_60

TRANSDUCER	READING (N)					
LONG	1.13	2.58	4.51	3.22	1.29	-.32
HOR	4.29	9.09	14.93	10.81	5.66	-.51
VER	6.19	9.97	14.44	9.63	3.78	-.34
T'V	3.25	4.36	5.34	3.22	.51	-.08
T'L	-.91	-1.83	-2.74	-1.83	-1.37	0.00
NOR	7.18	13.92	21.44	15.07	7.12	-.79

ALPHA	23.	THETA	60.			
	APPLIED	MEASURED	RATIO	DIFF (N)		
FORCES IN X	.95	1.13	1.18	.2		
Y	4.58	4.29	.94	-.3		
Z	6.41	6.19	.97	-.2		
TOT	7.94	7.61	.96	-.3		
APPLIED FRICTION RATIO		.47				
FORCES IN X	2.18	2.58	1.18	.4		
Y	9.80	9.09	.93	-.7		
Z	10.73	9.97	.93	-.8		
TOT	14.70	13.74	.93	-1.0		
APPLIED FRICTION RATIO		.34				
FORCES IN X	3.69	4.51	1.22	.8		
Y	15.70	14.93	.95	-.8		
Z	15.34	14.44	.94	-.9		
TOT	22.26	21.25	.95	-1.0		
APPLIED FRICTION RATIO		.28				
FORCES IN X	2.79	3.22	1.15	.4		
Y	11.25	10.81	.96	-.4		
Z	10.32	9.63	.93	-.7		
TOT	15.52	14.83	.96	-.7		
APPLIED FRICTION RATIO		.25				
FORCES IN X	1.05	1.29	1.23	.2		
Y	5.97	5.66	.95	-.3		
Z	4.00	3.78	.94	-.2		
TOT	7.27	6.93	.95	-.3		
APPLIED FRICTION RATIO		.21				
FORCES IN X	-.25	-.32	1.28	-.1		
Y	-.59	-.51	.87	.1		
Z	-.47	-.34	.74	.1		
TOT	.80	.70	.88	-.1		
APPLIED FRICTION RATIO		-.10				

ARCTEC CANADA LTD.

PROJECT 1566C

CALIBRATION RIG CAL

FILE NAME HYS_23_60

JAN 7 1987

TRANSDUCER	READING (N)					
LONG	2.25	2.58	4.51	5.47	5.15	4.19
HOR	5.15	6.86	12.35	16.47	15.61	12.18
VER	4.47	7.56	12.03	15.13	11.69	8.59
T'V	1.59	3.19	4.76	5.33	2.92	1.61
T'L	-.46	-.91	-1.83	-2.74	-2.51	-1.83
NOR	7.34	10.73	17.87	23.41	20.39	15.83

ALPHA	23.	THETA	60.			
		APPLIED	MEASURED	RATIO	DIFF (N)	
FORCES IN X		1.75	2.25	1.29	.5	
Y		5.30	5.15	.97	-.2	
Z		5.04	4.47	.89	-.6	
TOT		7.52	7.18	.95	-.3	
APPLIED FRICTION RATIO			.23			
FORCES IN X		2.17	2.58	1.19	.4	
Y		7.44	6.86	.92	-.6	
Z		8.13	7.56	.93	-.6	
TOT		11.23	10.53	.94	-.7	
APPLIED FRICTION RATIO			.31			
FORCES IN X		3.44	4.51	1.31	1.1	
Y		12.77	12.35	.97	-.4	
Z		13.06	12.03	.92	-1.0	
TOT		18.59	17.82	.96	-.8	
APPLIED FRICTION RATIO			.29			
FORCES IN X		4.36	5.47	1.26	1.1	
Y		17.28	16.47	.95	-.8	
Z		16.32	15.13	.93	-1.2	
TOT		24.16	23.02	.95	-1.1	
APPLIED FRICTION RATIO			.26			
FORCES IN X		4.02	5.15	1.28	1.1	
Y		15.90	15.61	.98	-.3	
Z		12.72	11.69	.92	-1.0	
TOT		20.75	20.17	.97	-.6	
APPLIED FRICTION RATIO			.19			
FORCES IN X		3.36	4.19	1.25	.8	
Y		12.59	12.18	.97	-.4	
Z		9.31	8.59	.92	-.7	
TOT		16.01	15.48	.97	-.5	

D-82

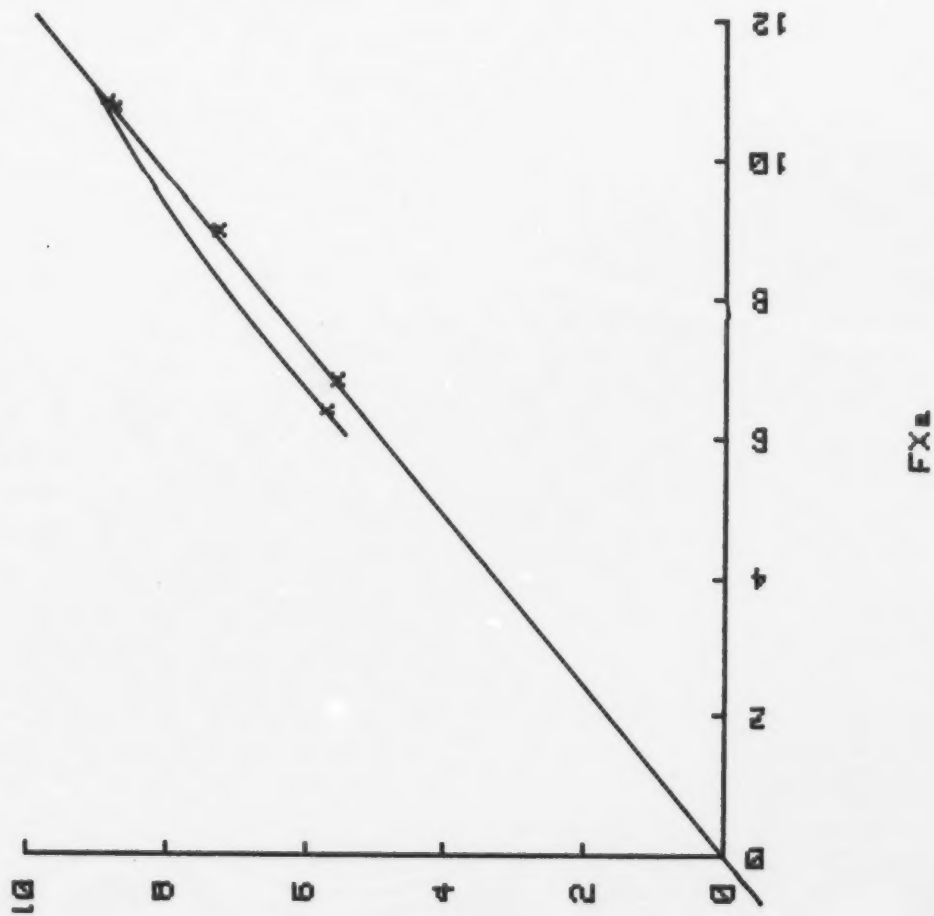
APPENDIX E

**RESULTS OF HYSTERESIS TESTS ON SEGMENTS 1, 2 AND 3 AND ON THE
CALIBRATION RIG**

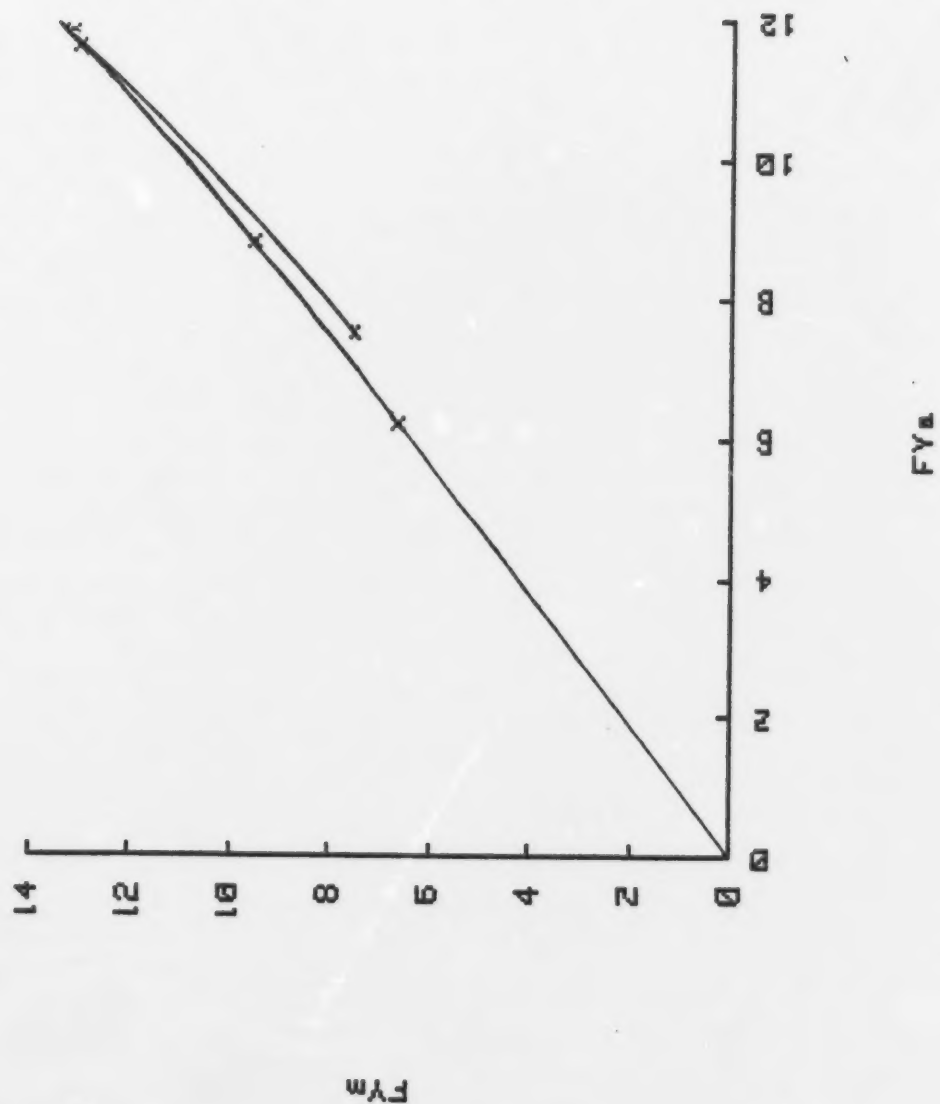
E.1 HYSTERESIS PLOTS OF SEGMENT 1

In this appendix the results of the two hysteresis tests at calibration points 28 and 30 on Segment 1 have been presented in graph form. For each test the following have been graphed as measured against applied: forces in the x direction, F_X , forces in the y direction, F_Y , forces in the z direction, F_Z , and total forces, F_{TOT} . The letters m and a on the forces in the plots indicate whether the load was that applied or that measured. All measurements are in Newtons. For example F_{Xm} was the force in Newtons measured by the segment in the x direction. The curves through the data points were used to calculate the hysteresis and nonlinearity present in the data from the formulas given in Appendix F.

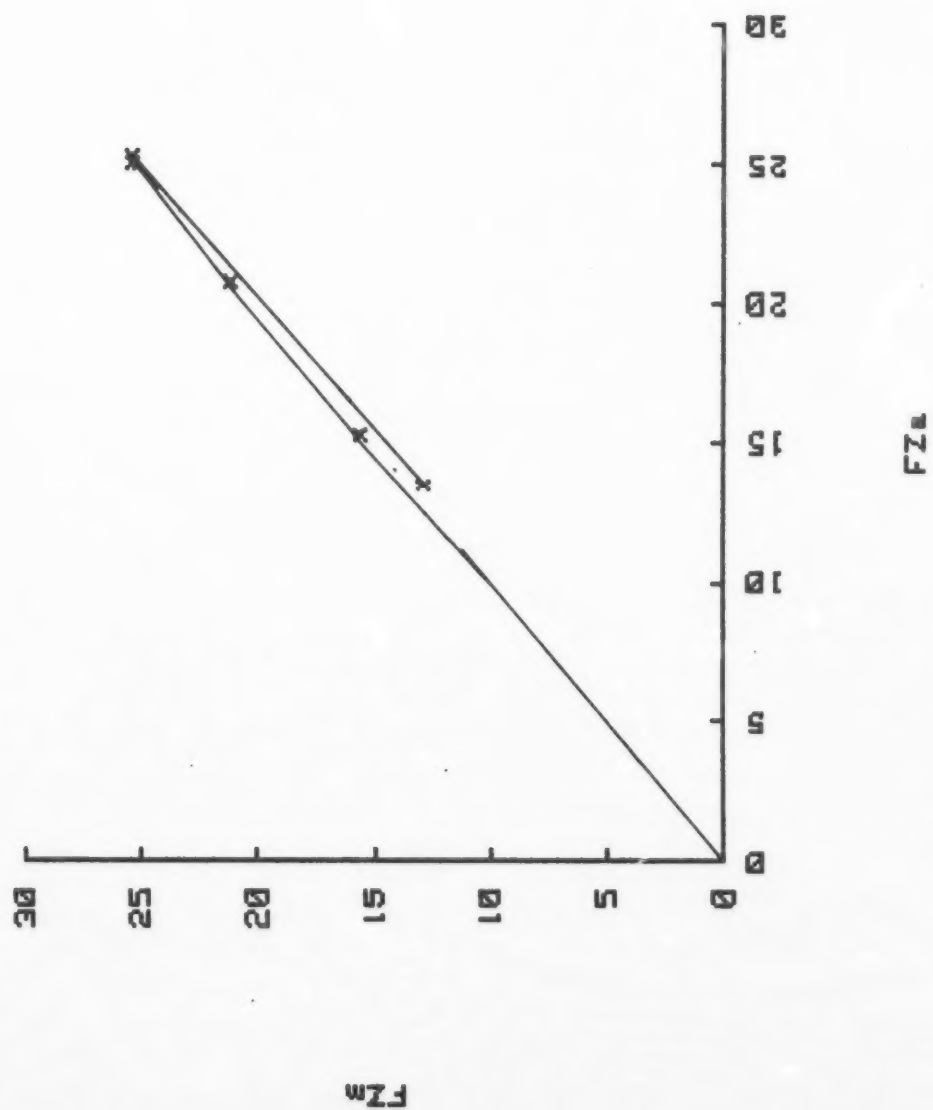
HYSTERESIS OF SEG 1 POSITION 2B: FORCES IN X



HYSTERESIS OF SEG 1 POSITION 2B: FORCES IN Y



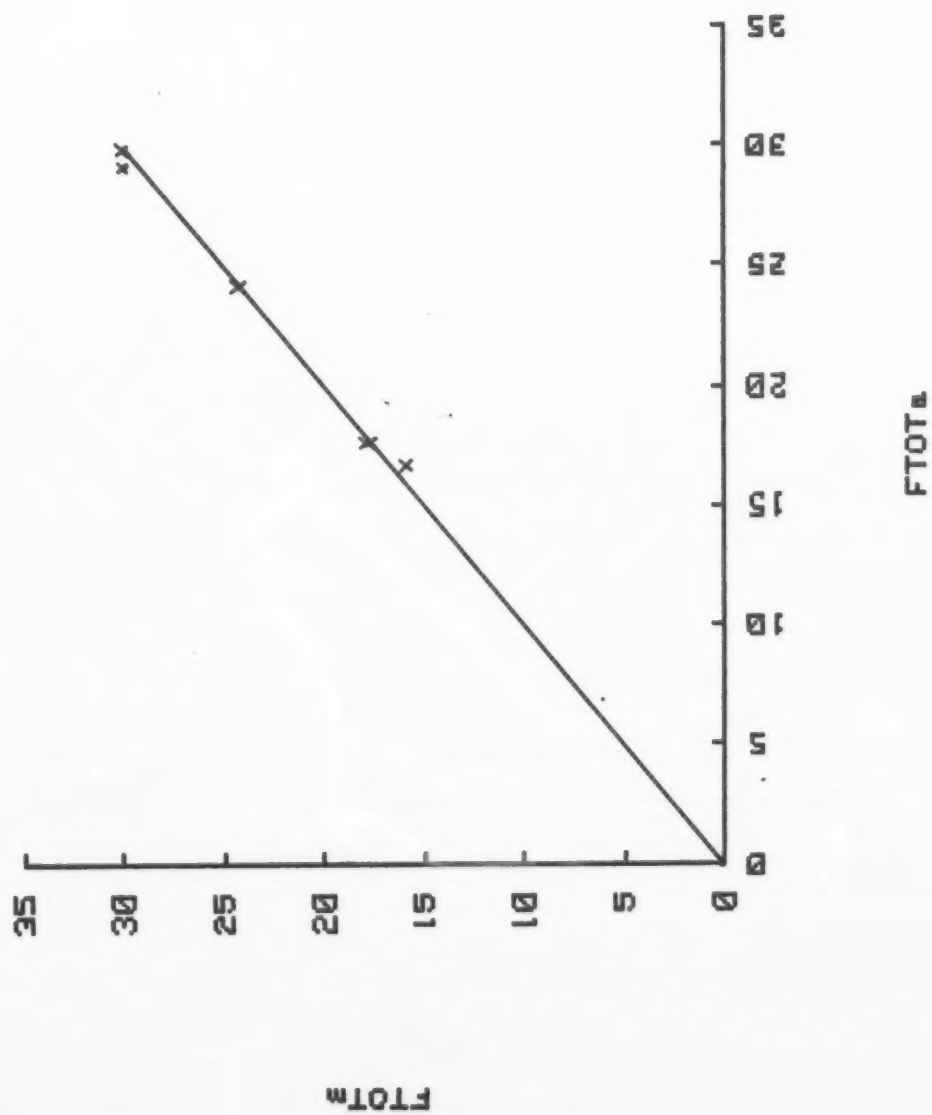
HYSTERESIS ON SEG 1 POSITION 2B: FORCES IN Z



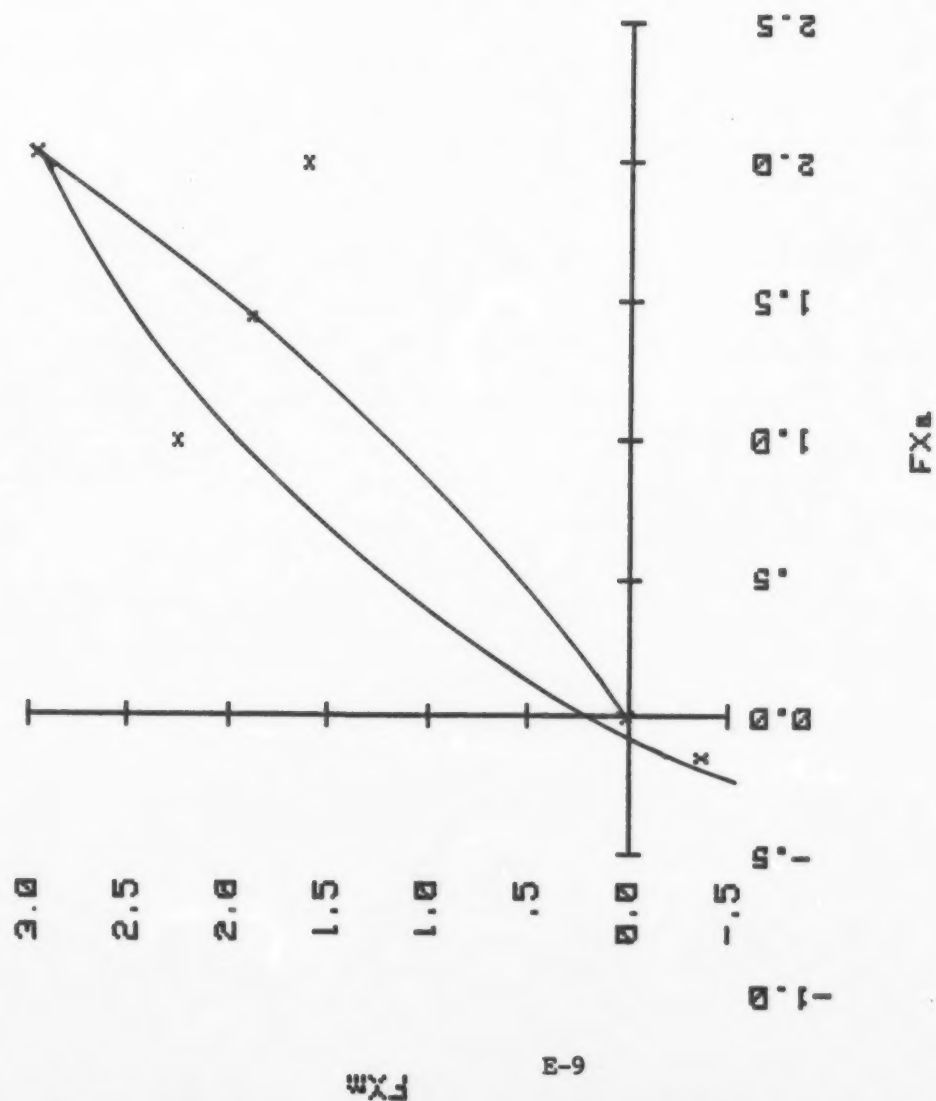
FZ_m

7-3

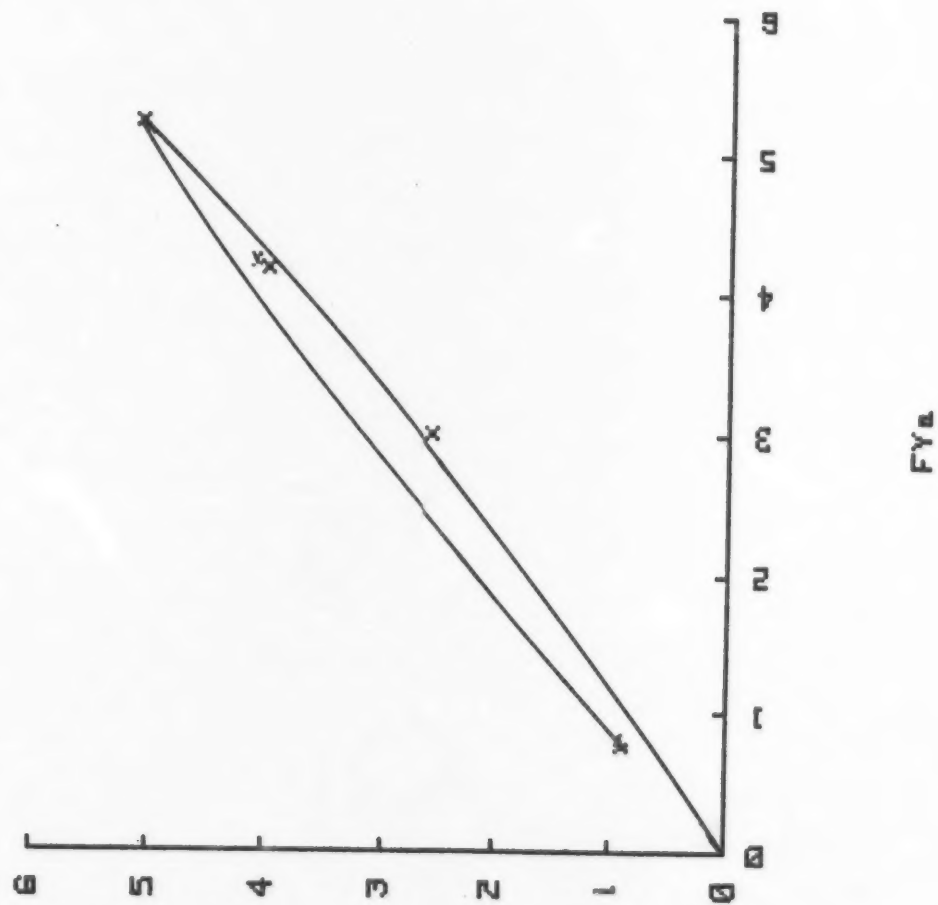
HYSTERESIS OF SEG 1 POSITION 2B: TOTAL FORCE



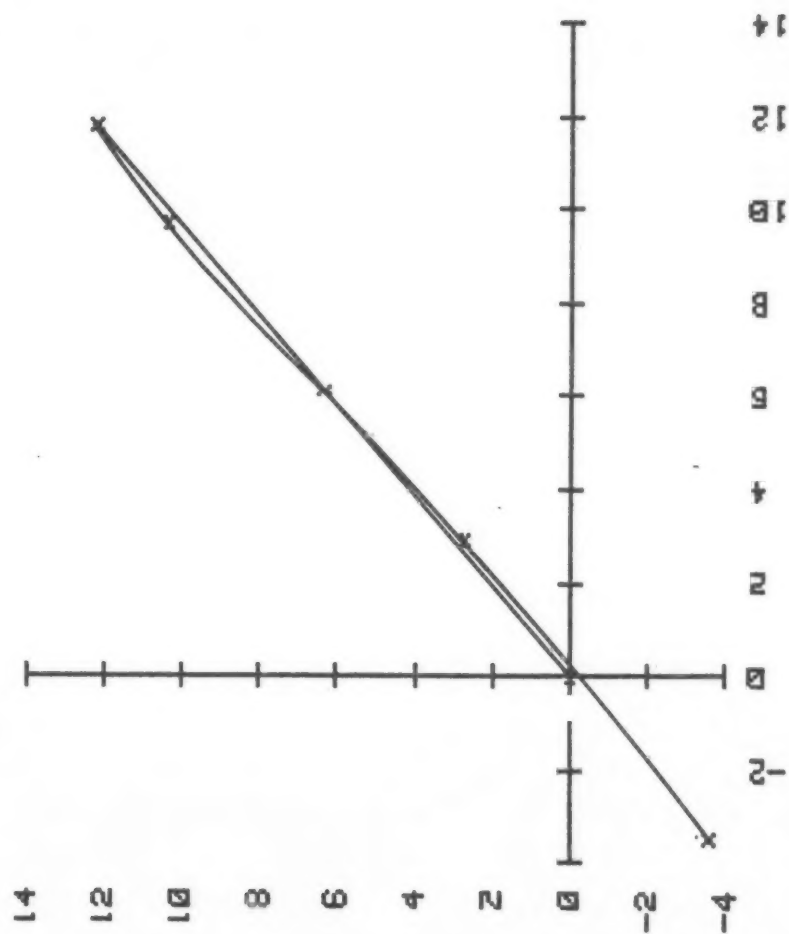
HYSTERESIS OF SEG 1 POSITION 30: FORCES IN X



HYSTERESIS ON SEG 1 POSITION 30: FORCES IN Y



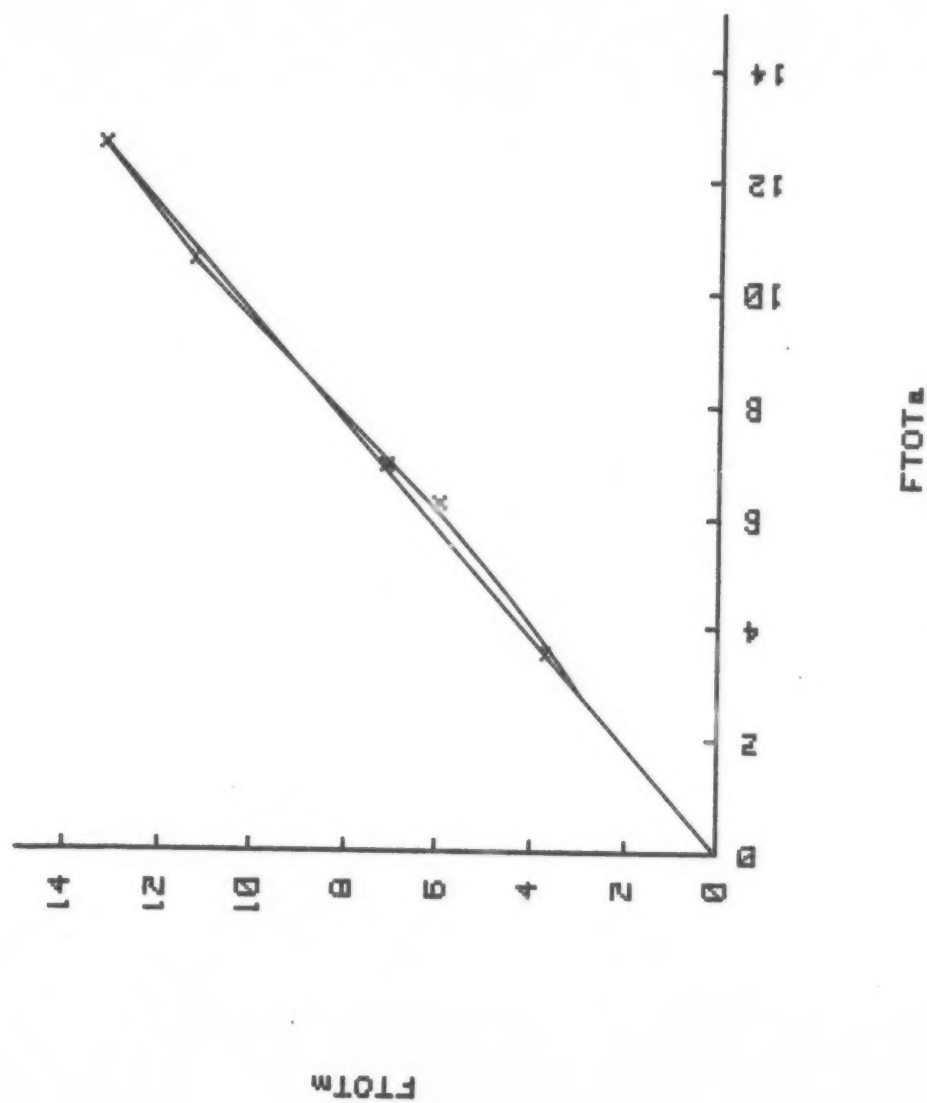
HYSTERESIS ON SEG 1 POSITION 30: FORCES IN Z



Fxm

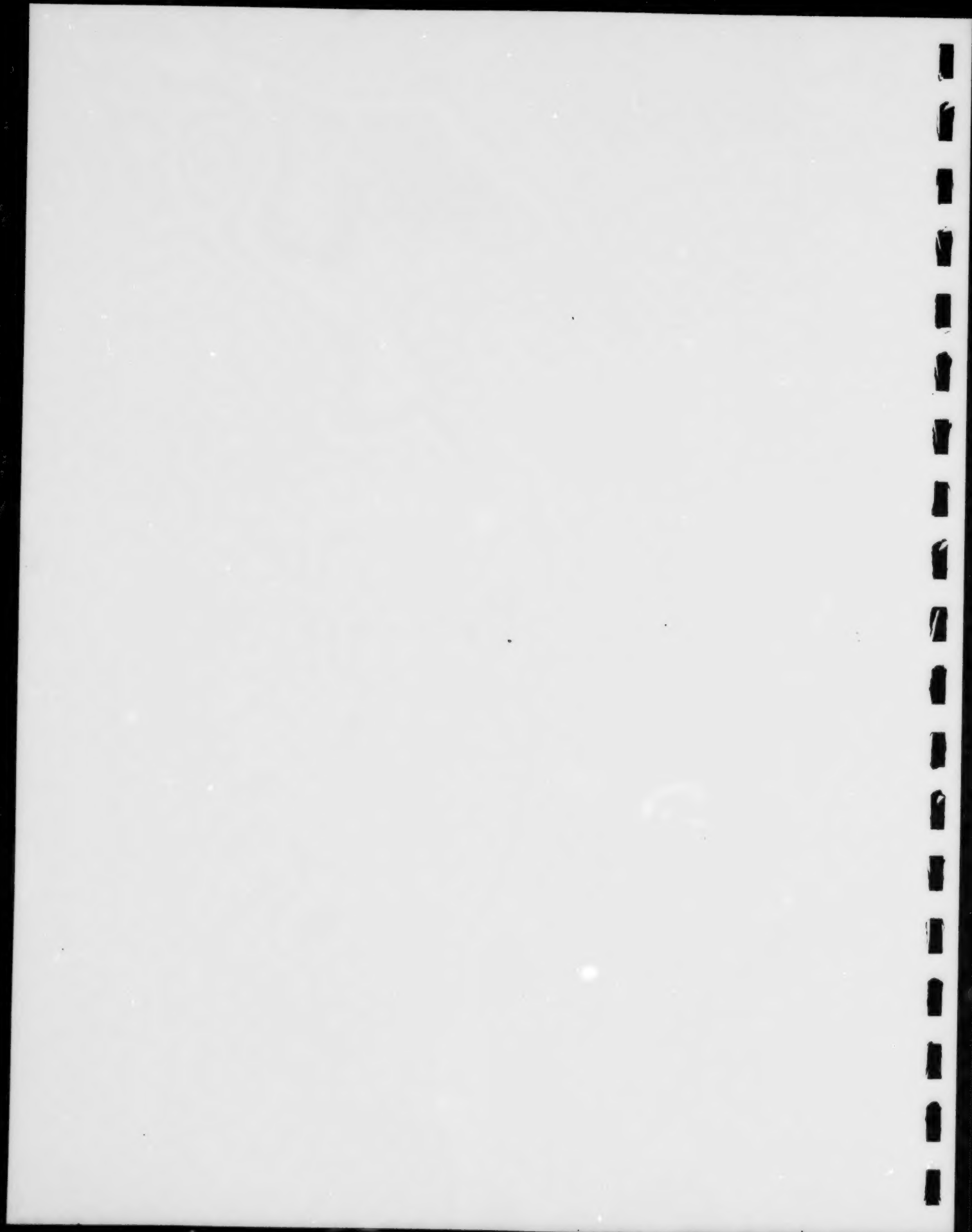
FZa

HYSTERESIS OF SEG 1 POSITION 30: TOTAL FORCE

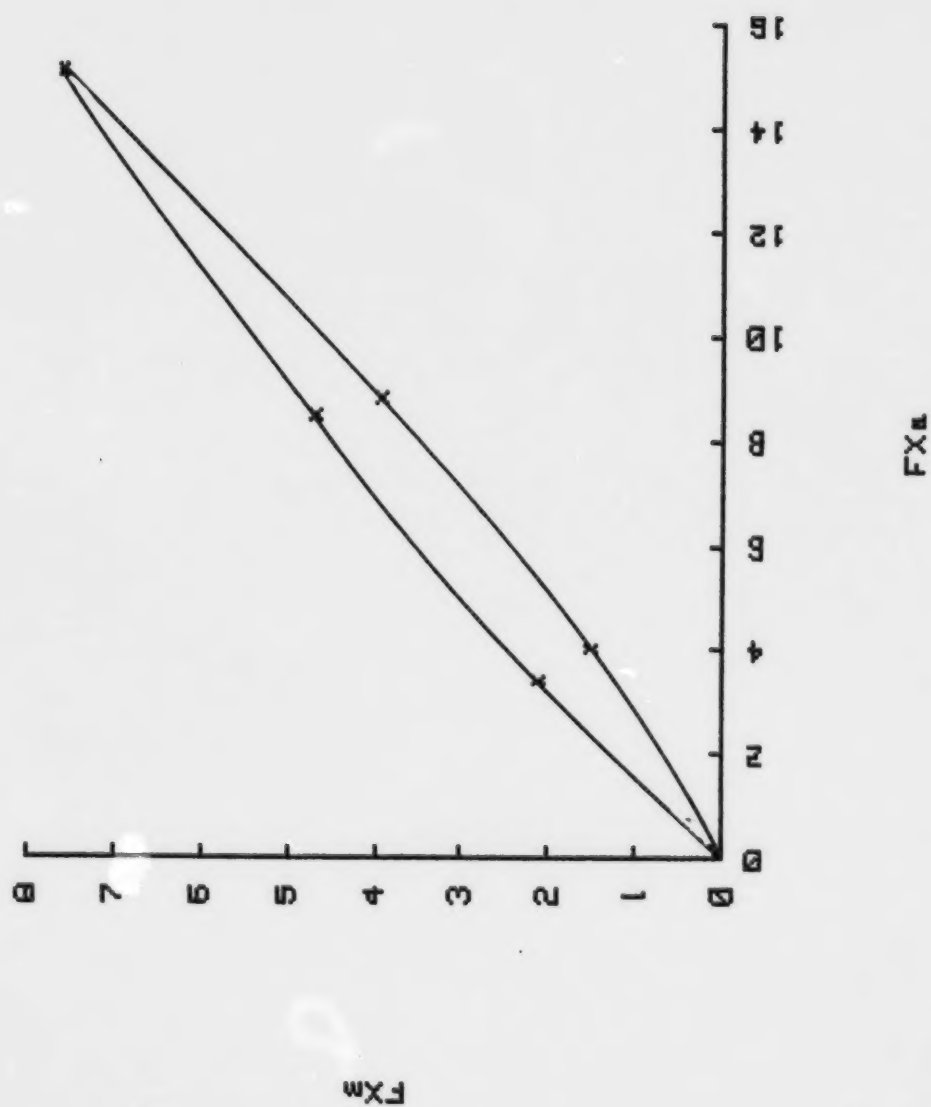


E.2 HYSTERESIS PLOTS OF SEGMENT 2

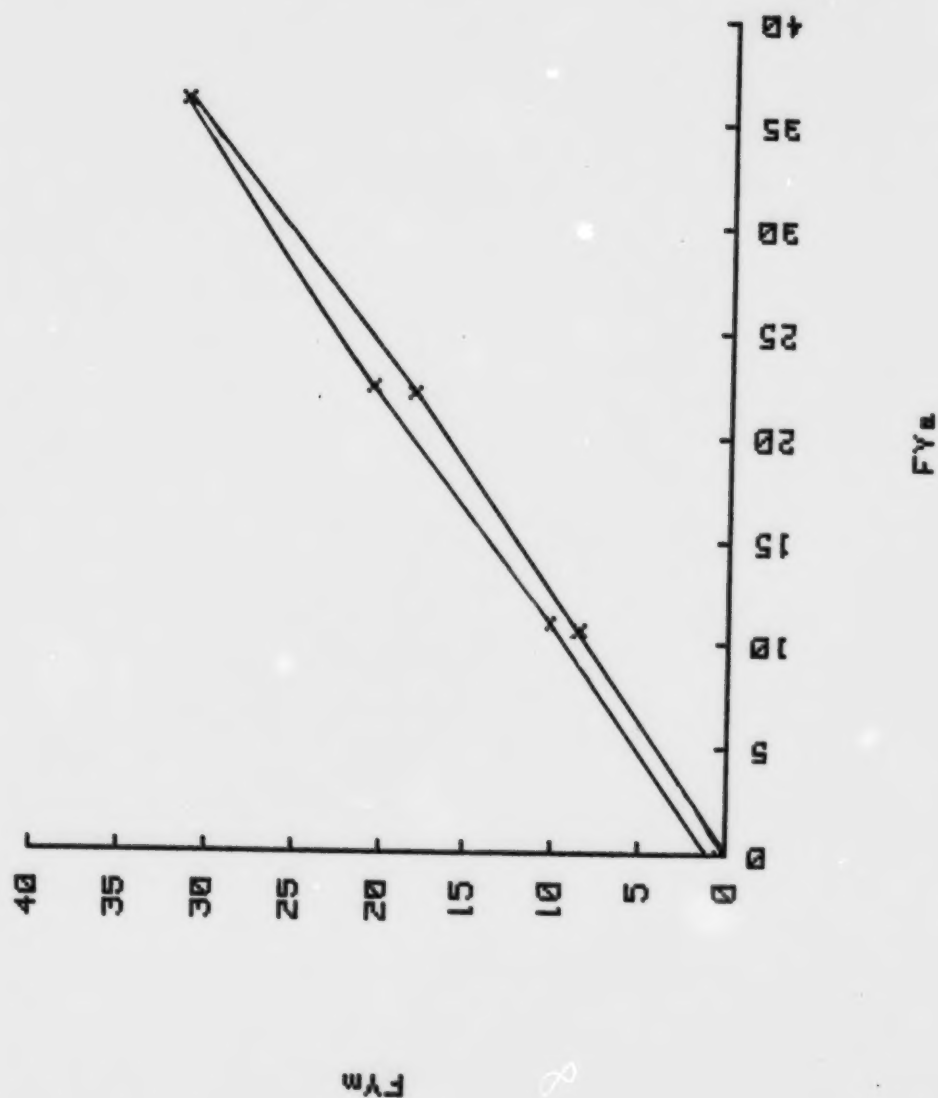
In this appendix the results of the hysteresis test at calibration points 5 on Segment 2 have been presented in graph form. For each test the following have been graphed as measured against applied: forces in the x direction, forces in the y direction, forces in the z direction and total forces. The curves through the data points were used to calculate the hysteresis and nonlinearity present in the data from the formulas given in Appendix F. Note that the test was done with all four vertical transducers present.



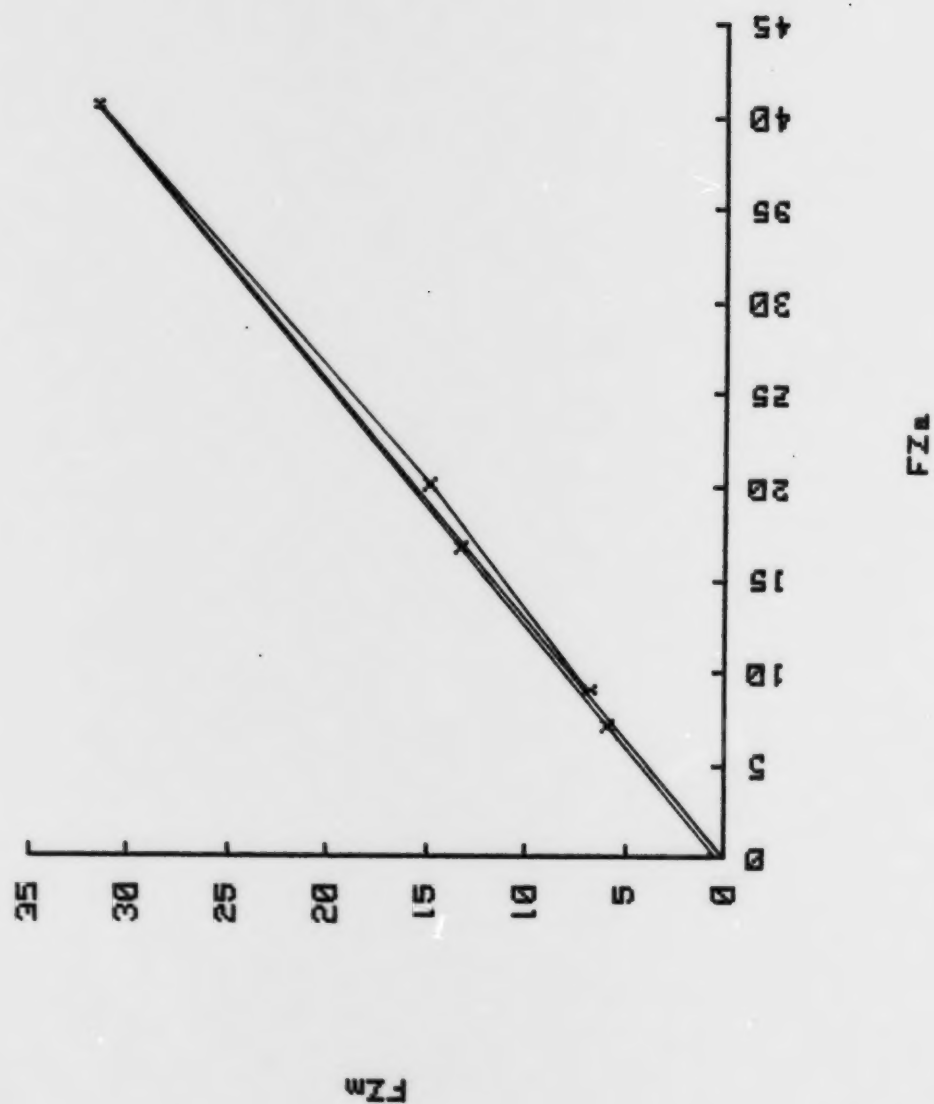
HYSTERESIS OF SEG 2 POSITION 5: FORCES IN X



HYSTERESIS OF SEG 2 POSITION 5: FORCES IN Y

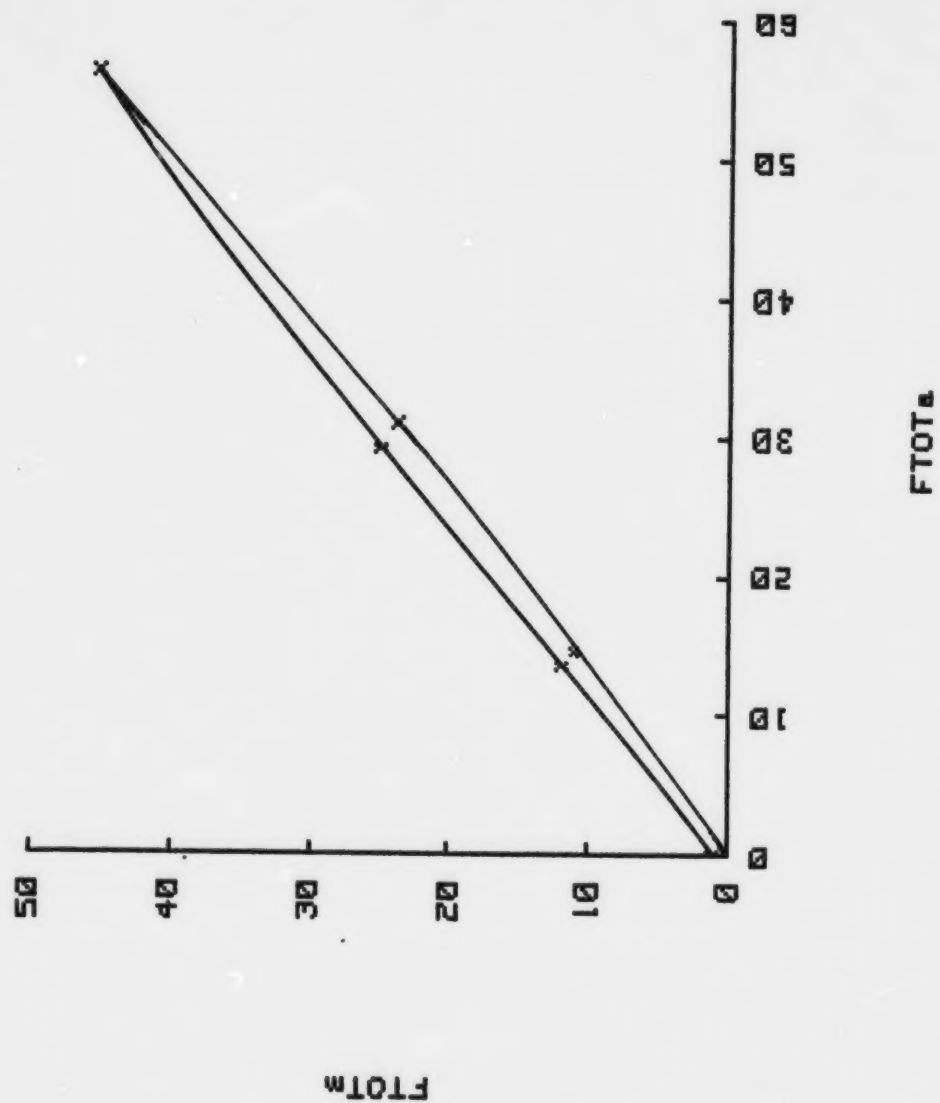


HYSTERESIS OF SEG 2 POSITION 5: FORCES IN Z



FZ_m

HYSTERESIS OF SEG 2: TOTAL FORCE

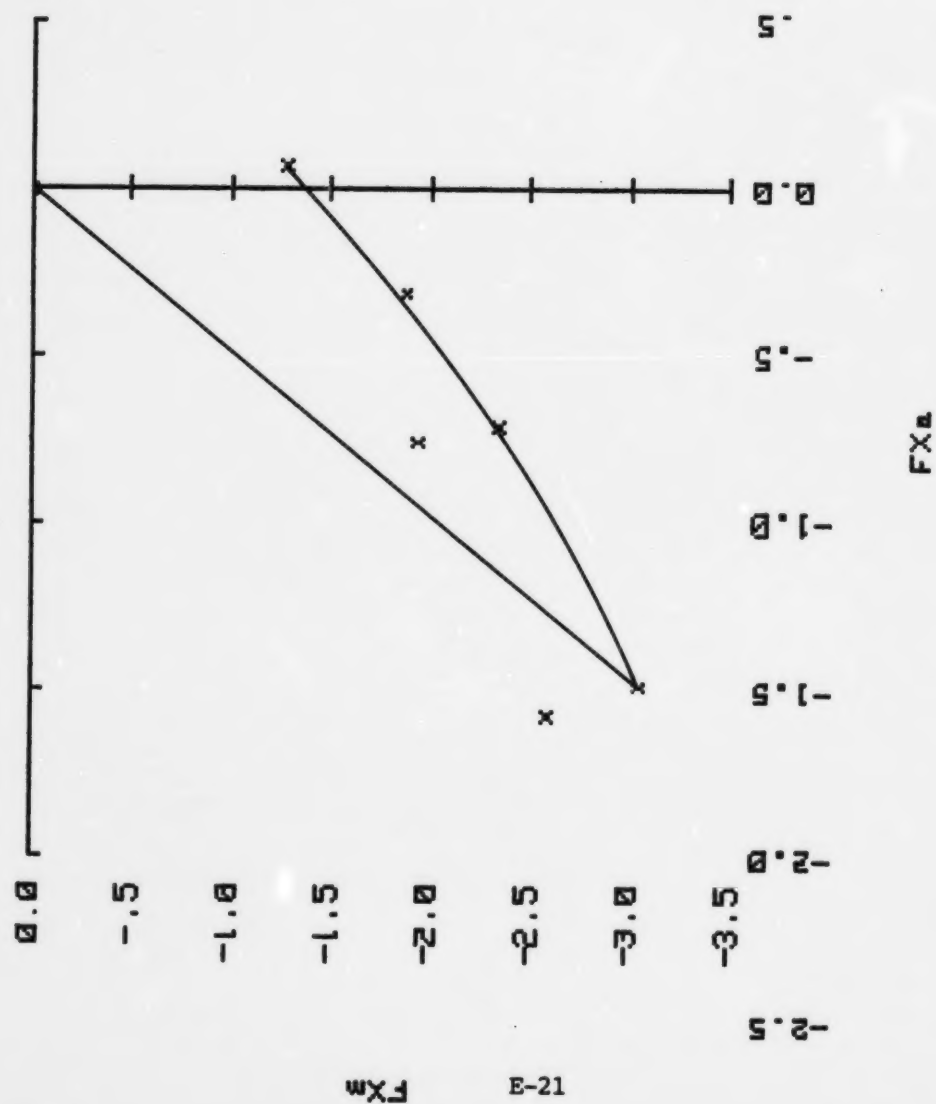


E.3 HYSTERESIS PLOTS OF SEGMENT 3

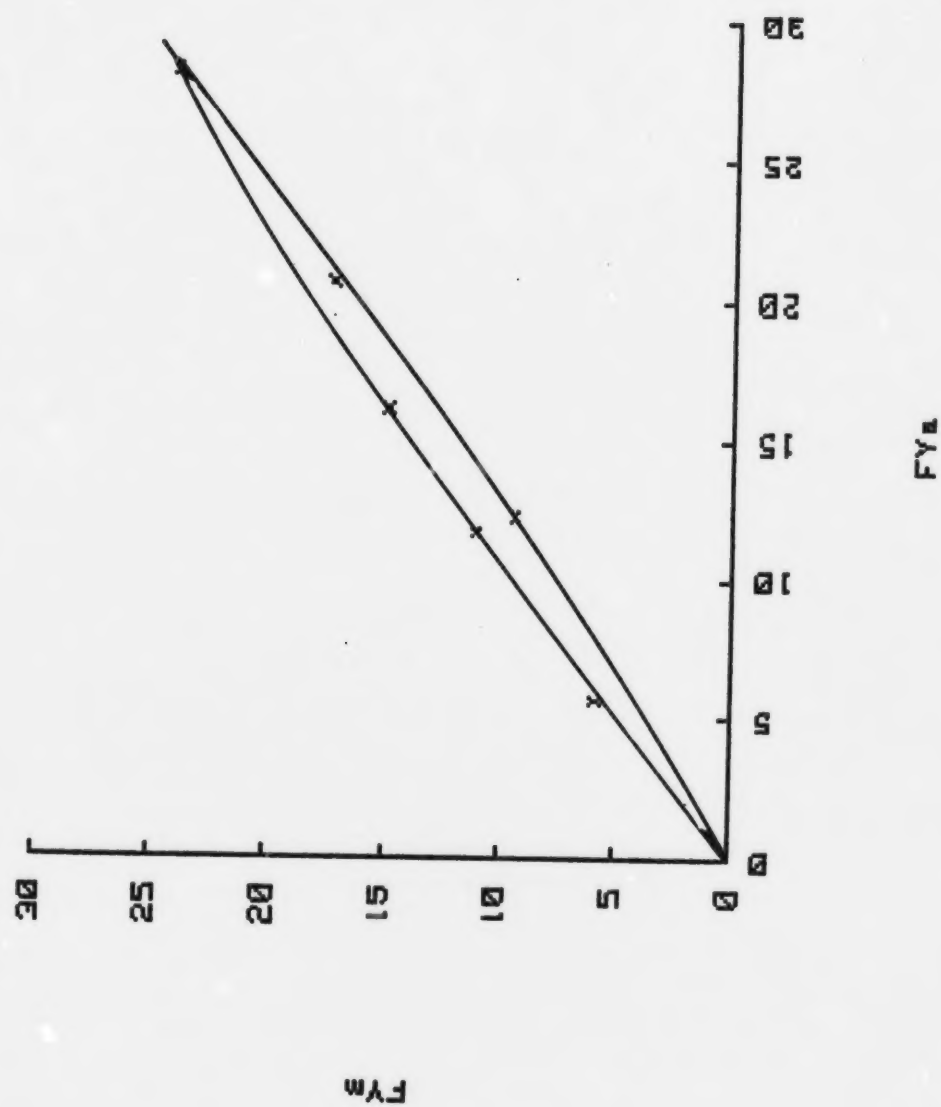
In this appendix the results of the two hysteresis tests at calibration points 47 and 49 on Segment 2 have been presented in graph form. For each test the following have been graphed as measured against applied: forces in the x direction, forces in the y direction, forces in the z direction and total forces. The curves through the data points have been used to calculate the hysteresis and nonlinearity present in the data from the formulas given in Appendix F.



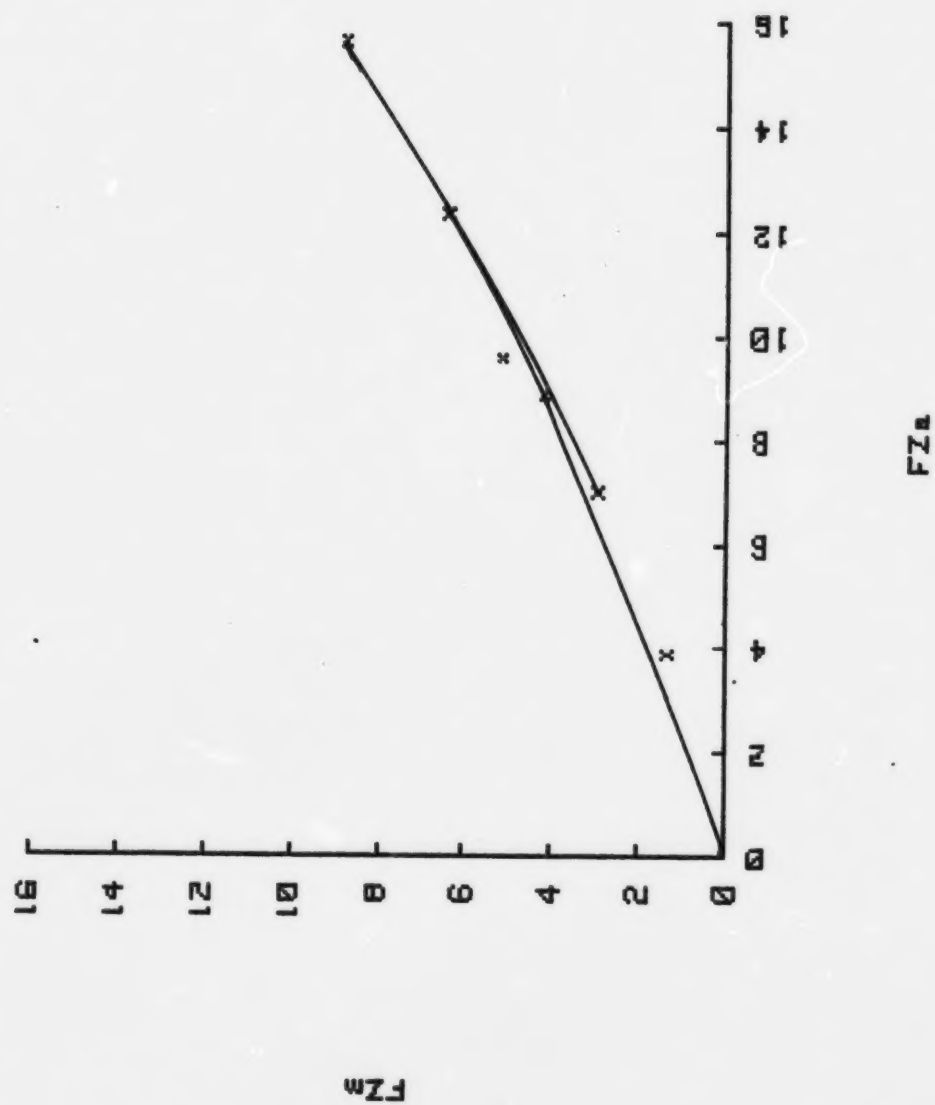
HYSTERESIS OF SEG 3 POSITION 47: FORCES IN X



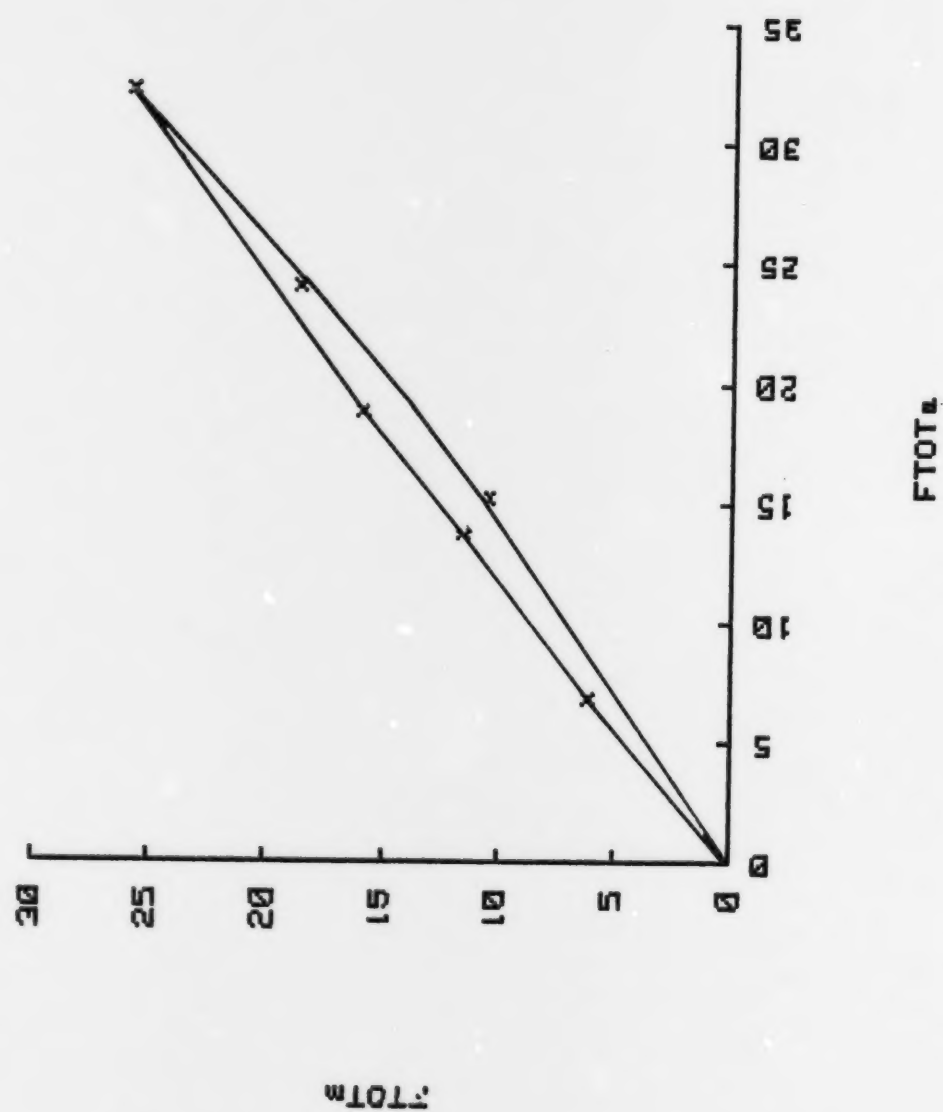
HYSTERESIS ON SEG 3 POSITION 47: FORCES IN Y



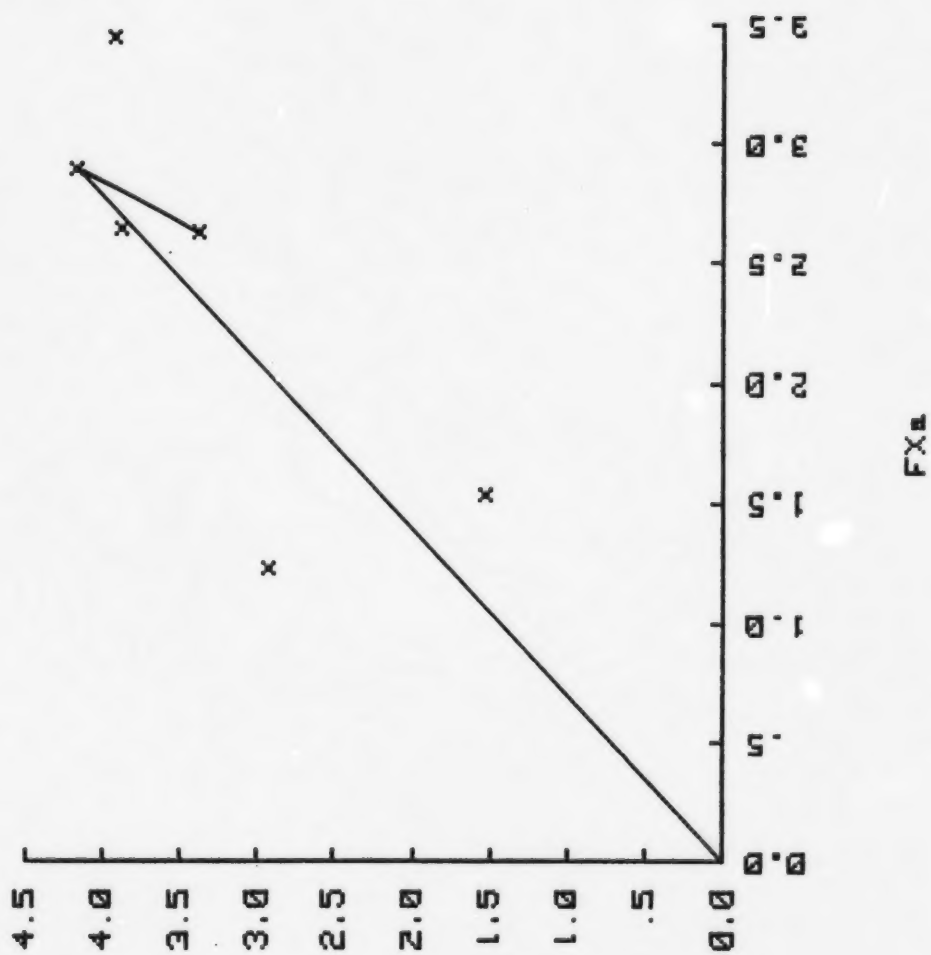
HYSTERESIS ON SEG 3 POSITION 47: FORCES IN Z



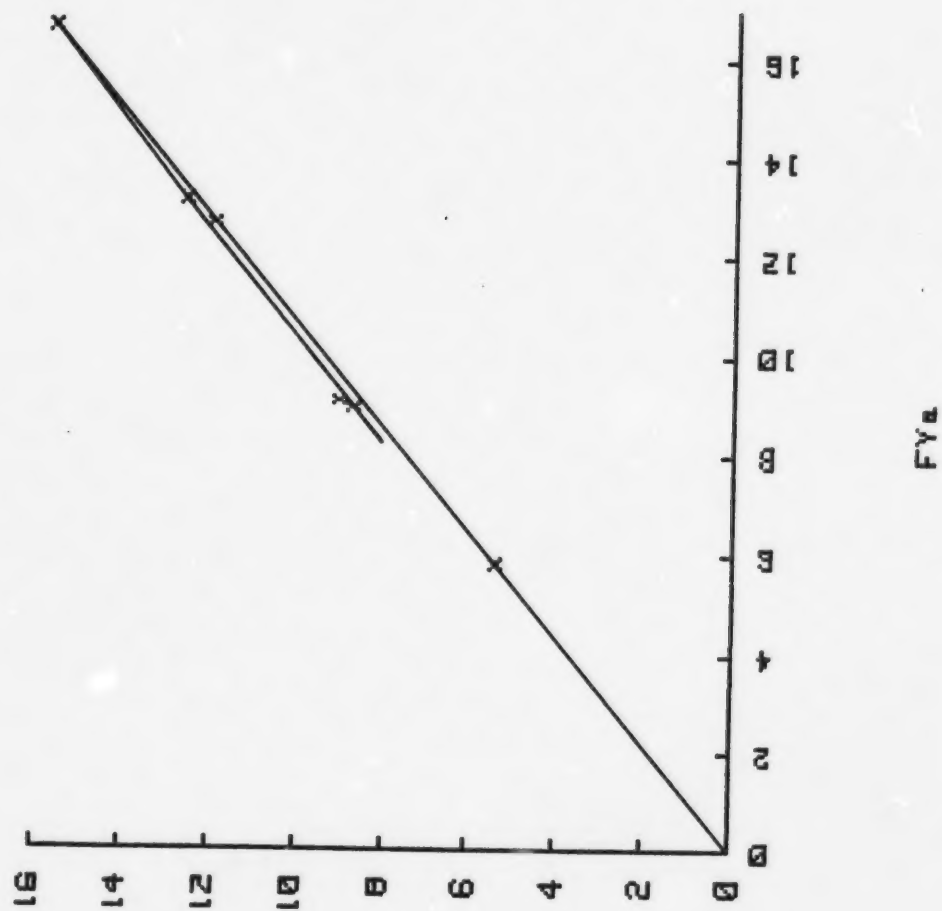
HYSTERESIS OF SEG 3 POSITION 47: TOTAL FORCE



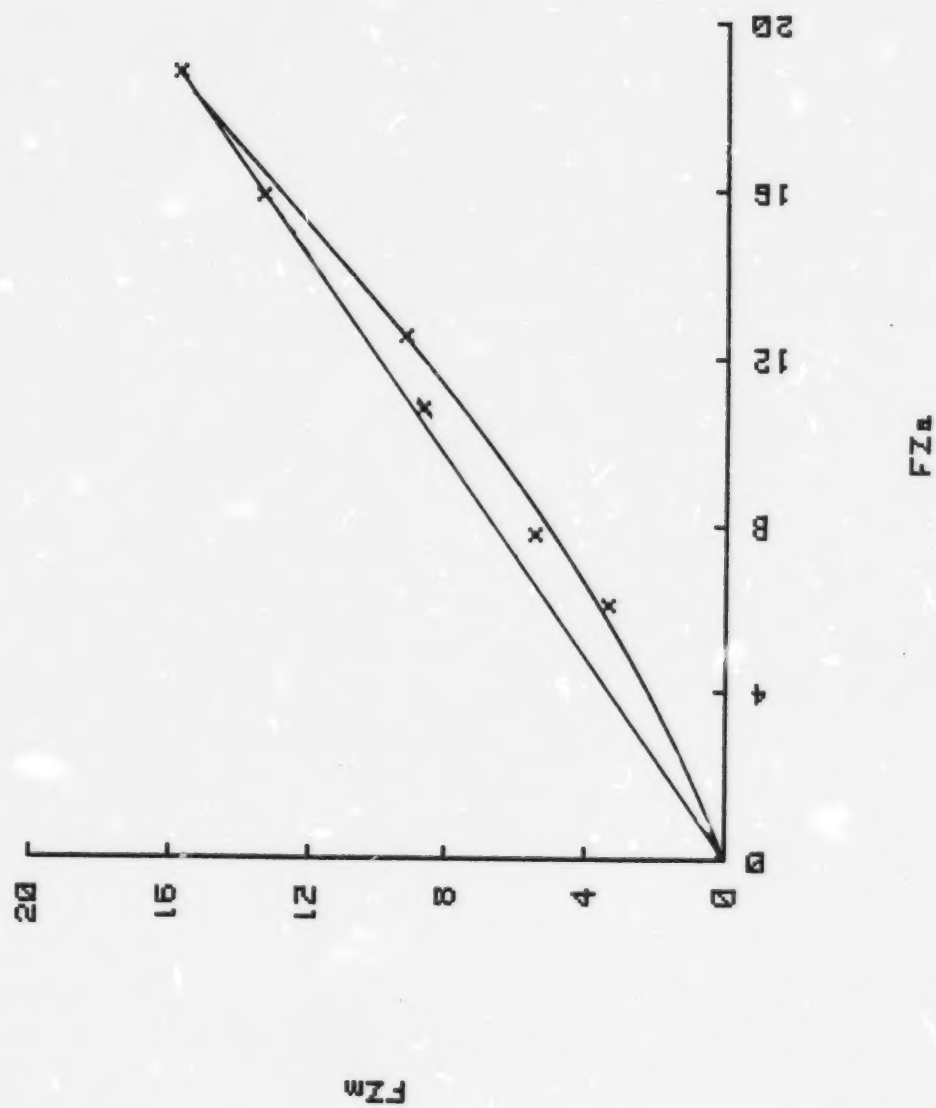
HYSTERESIS OF SEG 3 POSITION 49: FORCES IN X



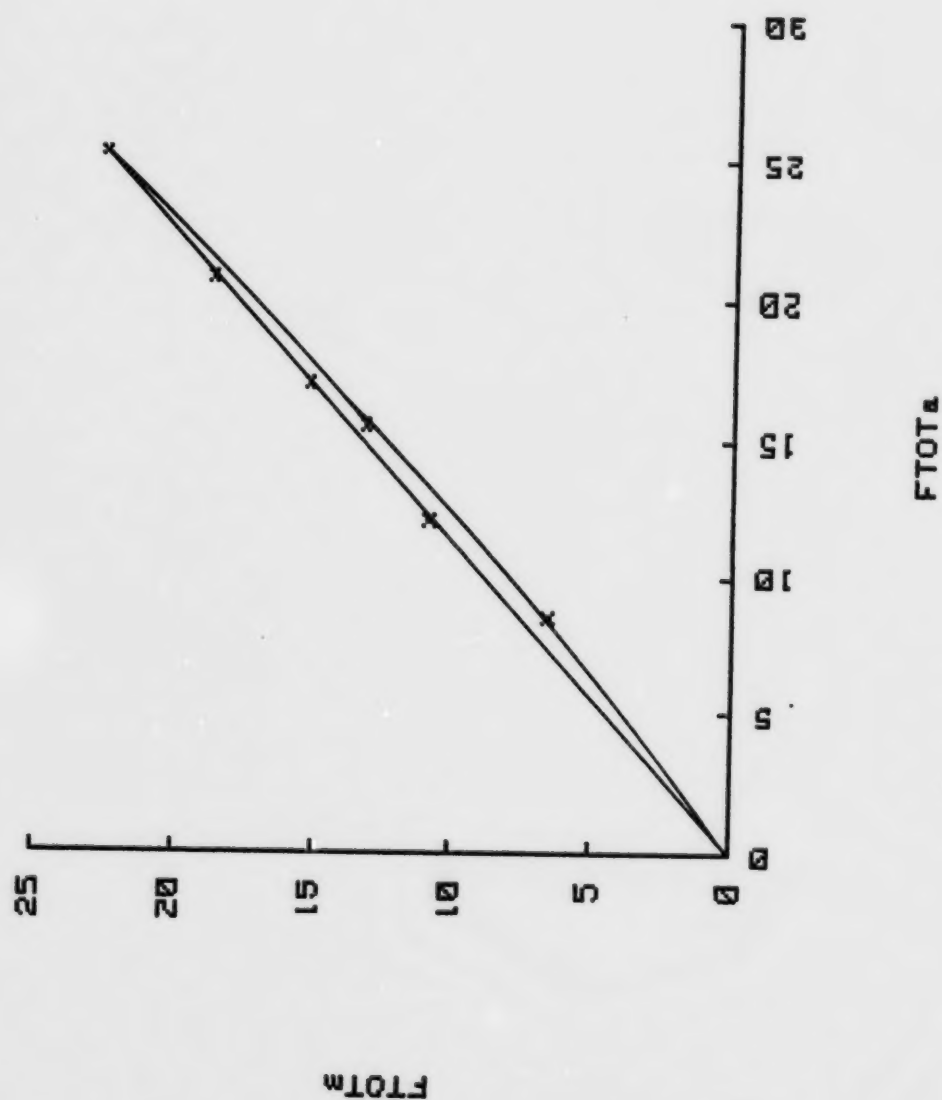
HYSTERESIS OF SEG 3 POSITION 49: FORCES IN Y



HYSTERESIS ON SEG 3 POSITION 49: FORCES IN Z

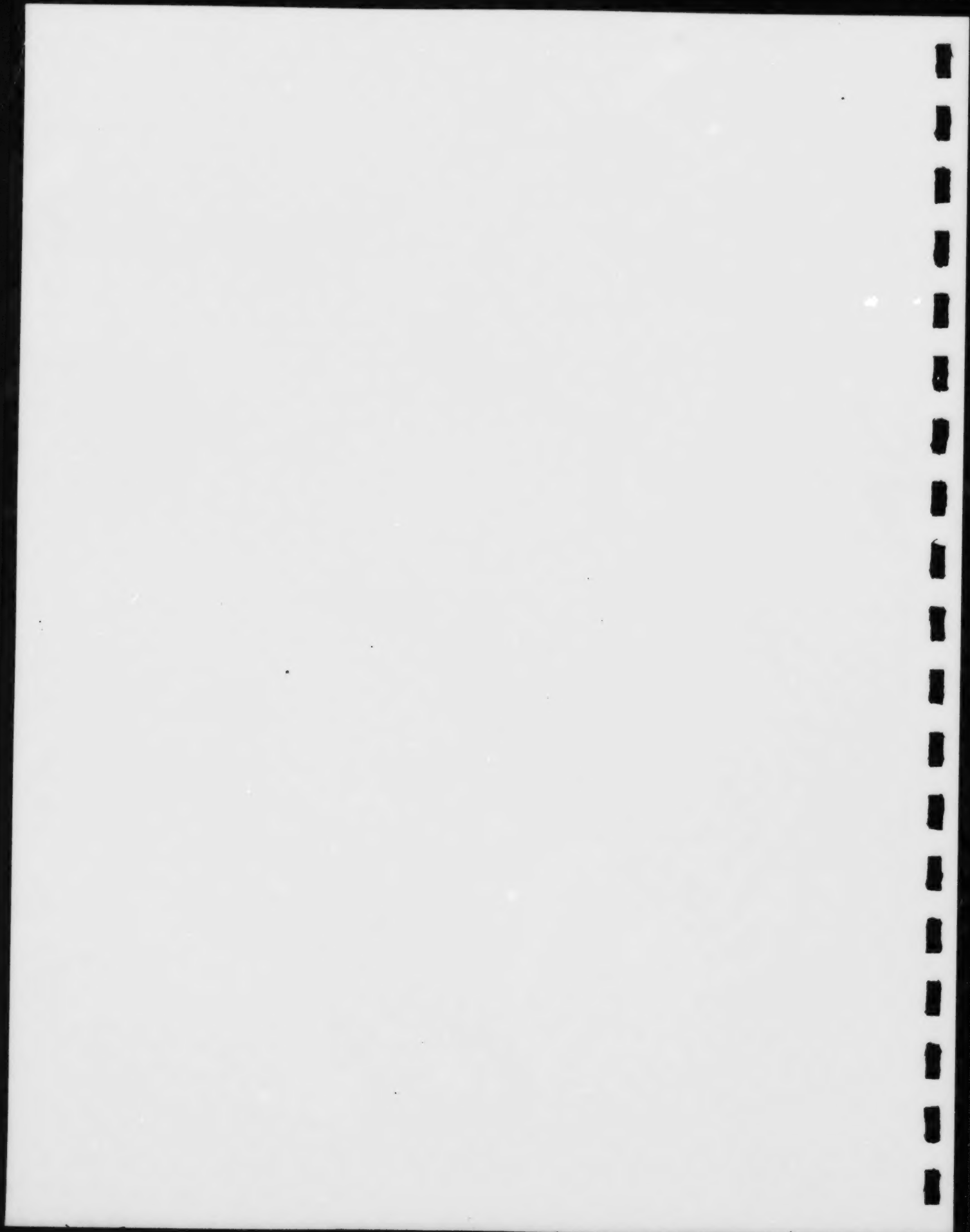


HYSTERESIS OF SEG 3 POSITION 49: TOTAL FORCE

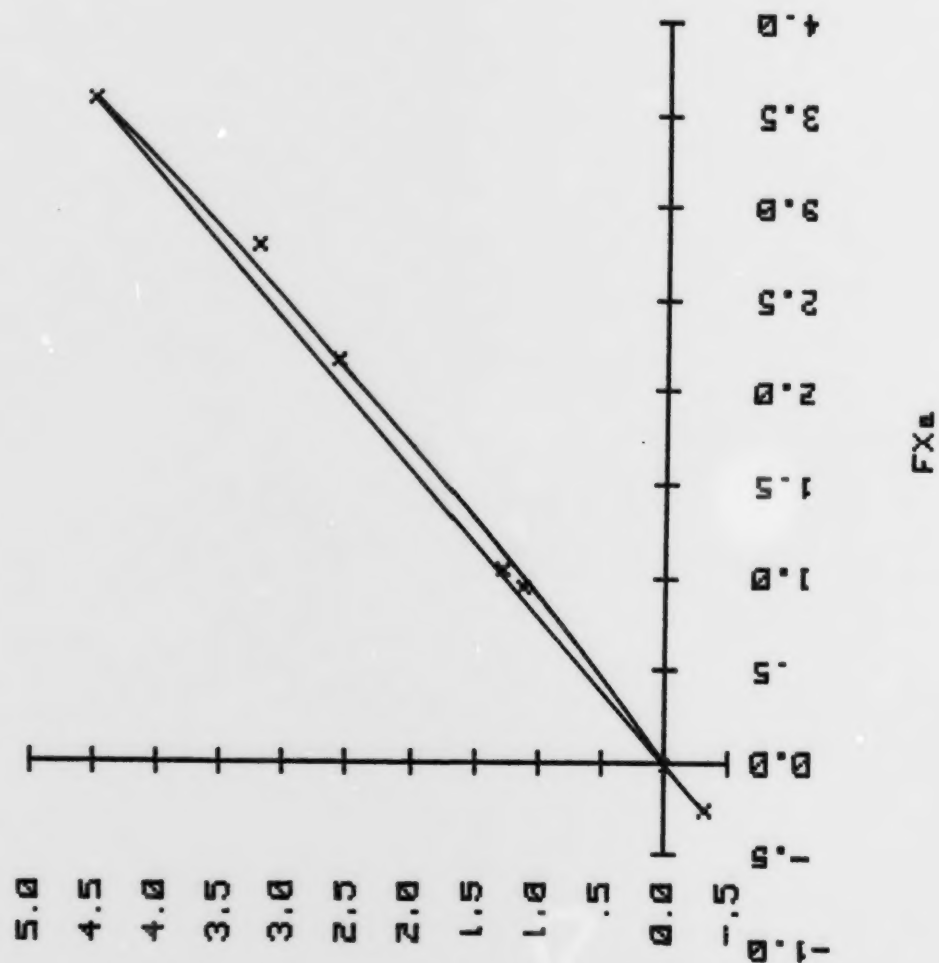


E.4 CALIBRATION RIG HYSTERESIS PLOTS

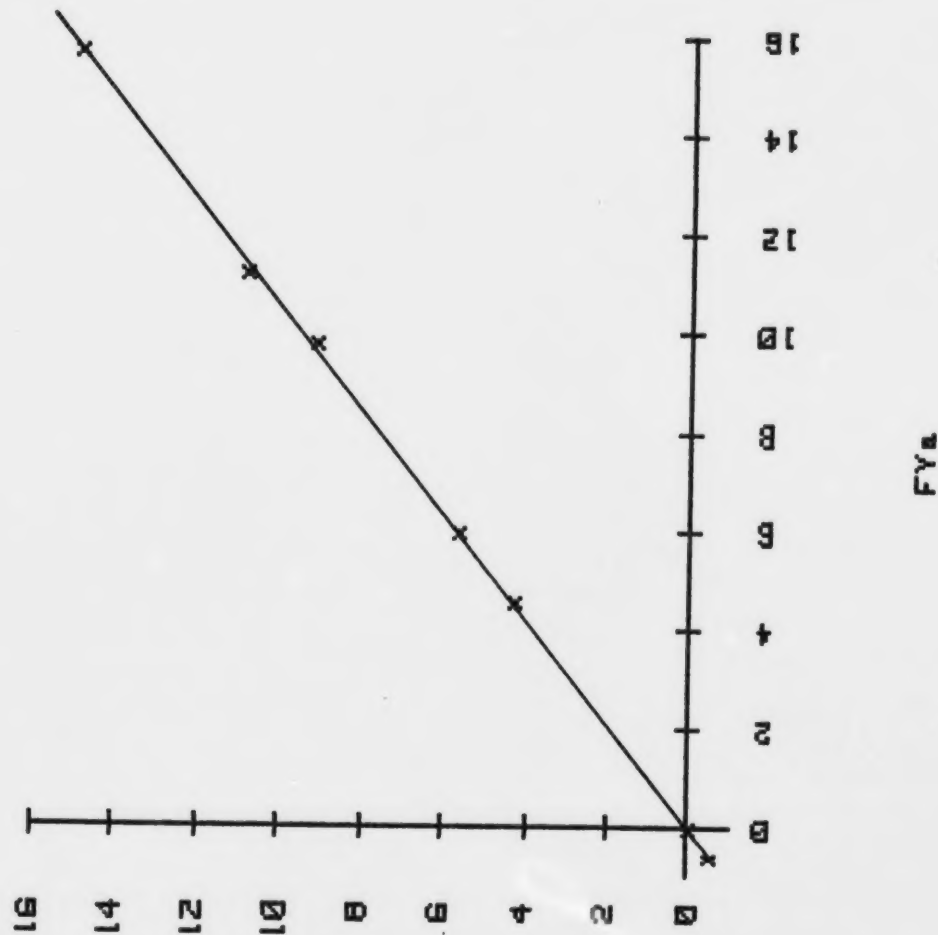
In this appendix the results of the two hysteresis tests of the calibration rig have been presented in graph form. For each test the following have been graphed as measured against applied: forces in the x direction, forces in the y direction, forces in the z direction and total forces. The curves through the data points were used to calculate the hysteresis and nonlinearity present in the data from the formulas given in Appendix F. The tests were conducted using the procedure for the calibration rig verification tests given in Section 4, Volume I.



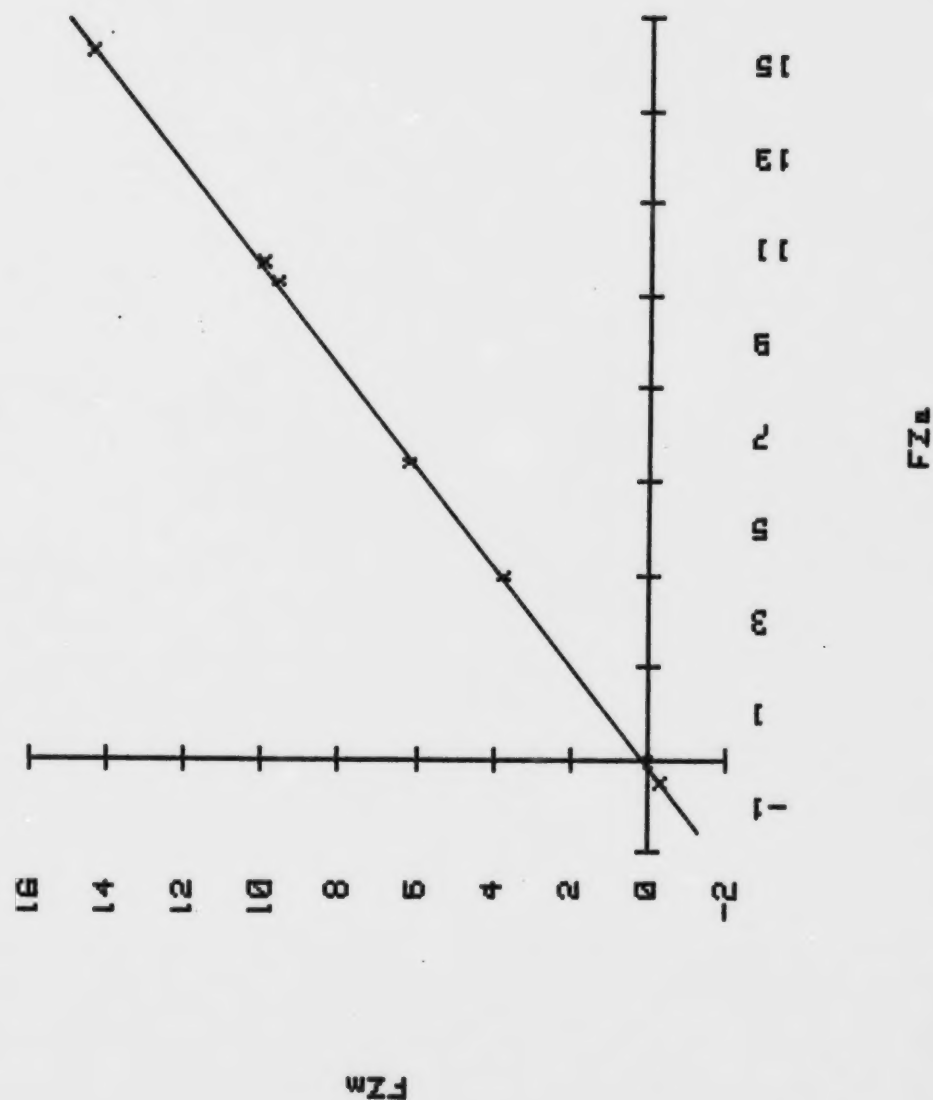
CAL. RIG HYSTERESIS AT Alpha=23 Theta=60



CAL. RIG HYSTERESIS AT Alpha=23 Theta=60

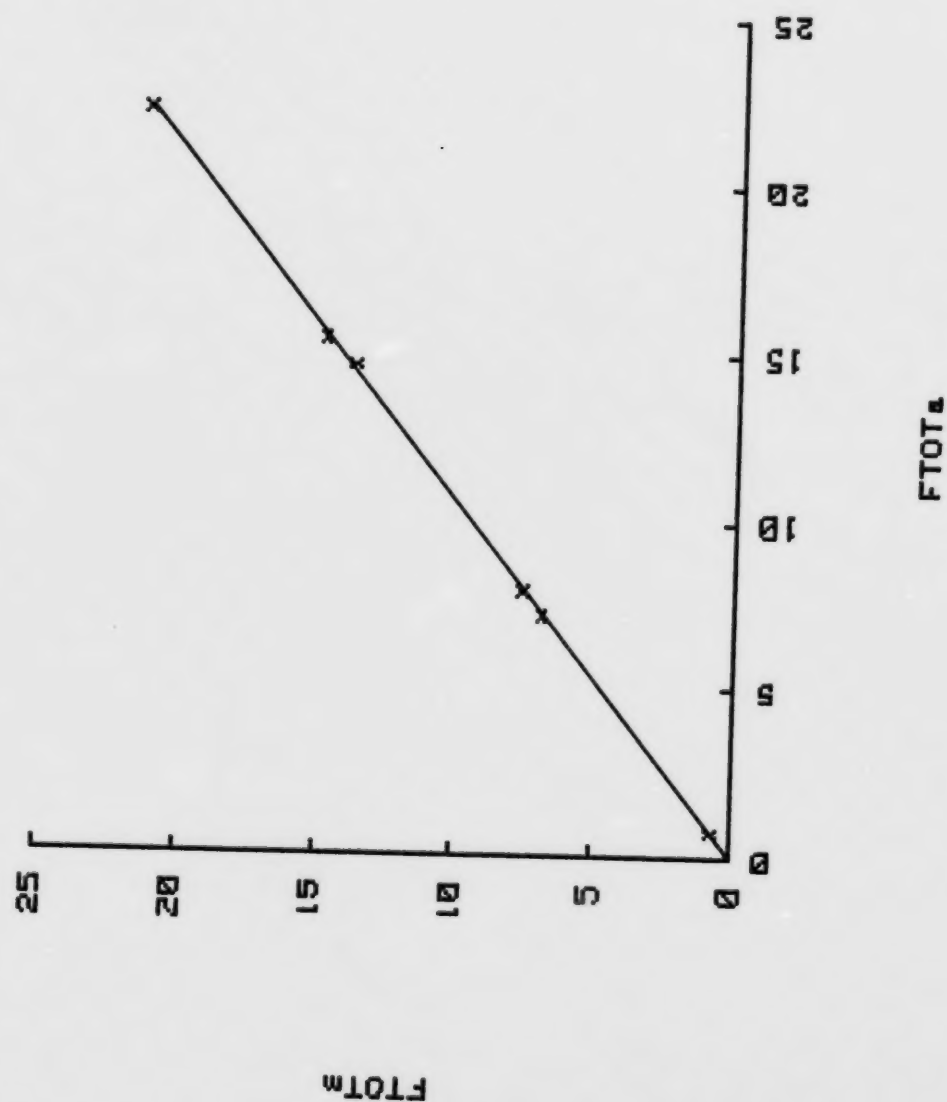


CAL. RIG HYSTERESIS AT $\alpha=23$ $\theta=60$

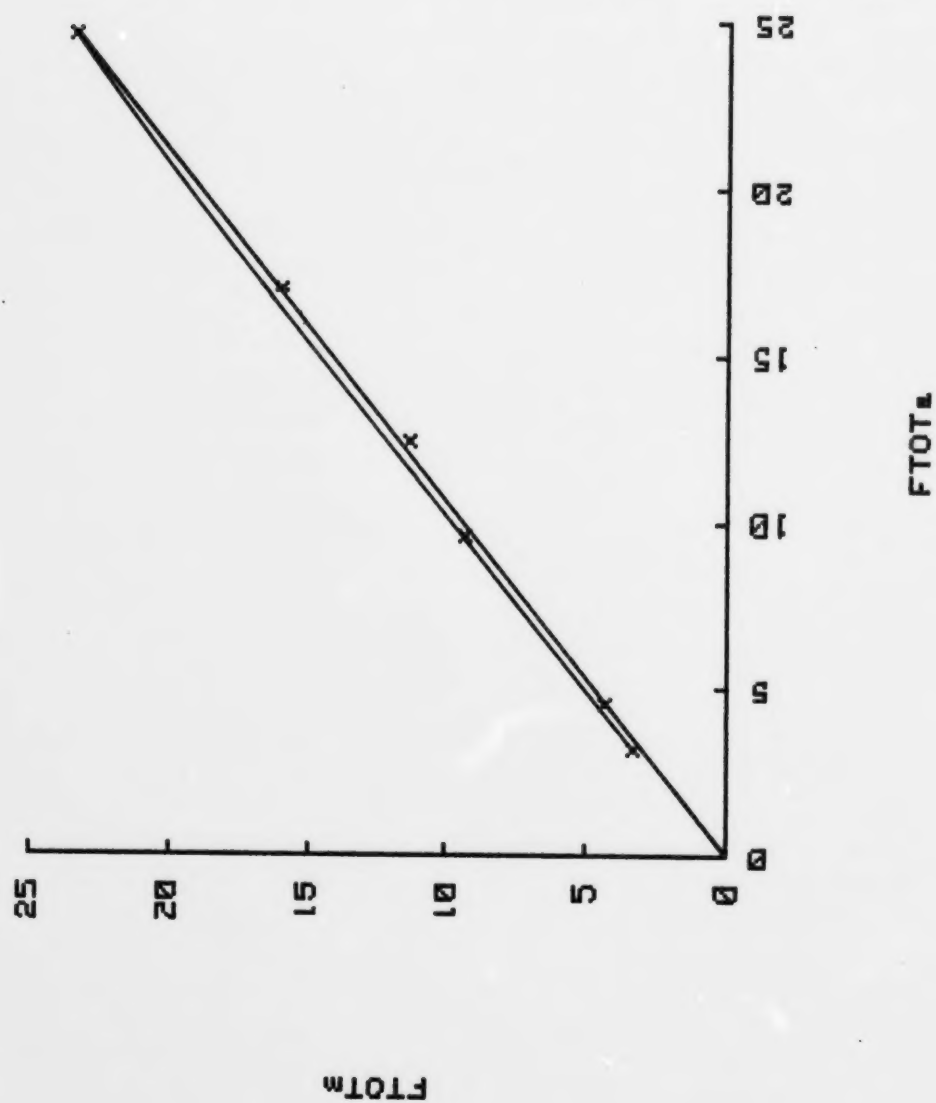


FZ_m

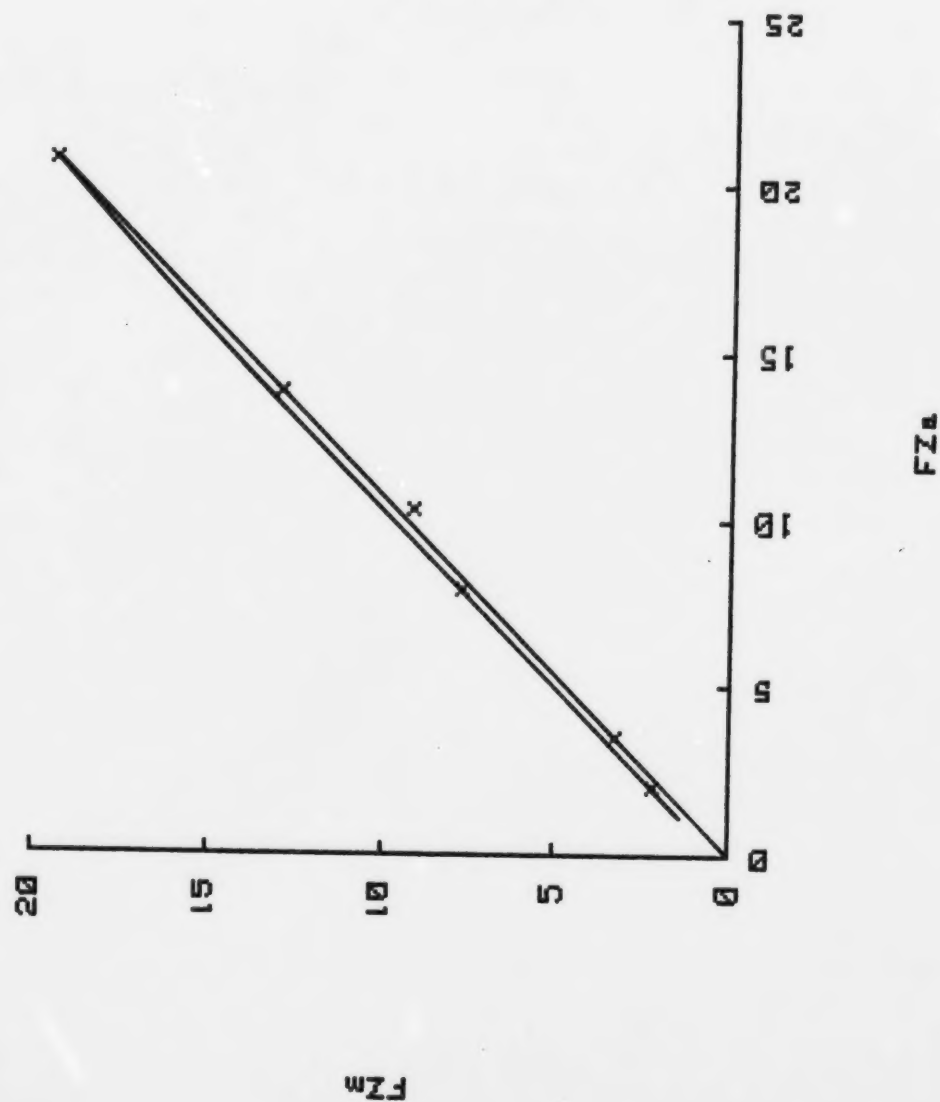
CAL. RIG HYSTERESIS AT $\alpha=23$ $\theta=60$



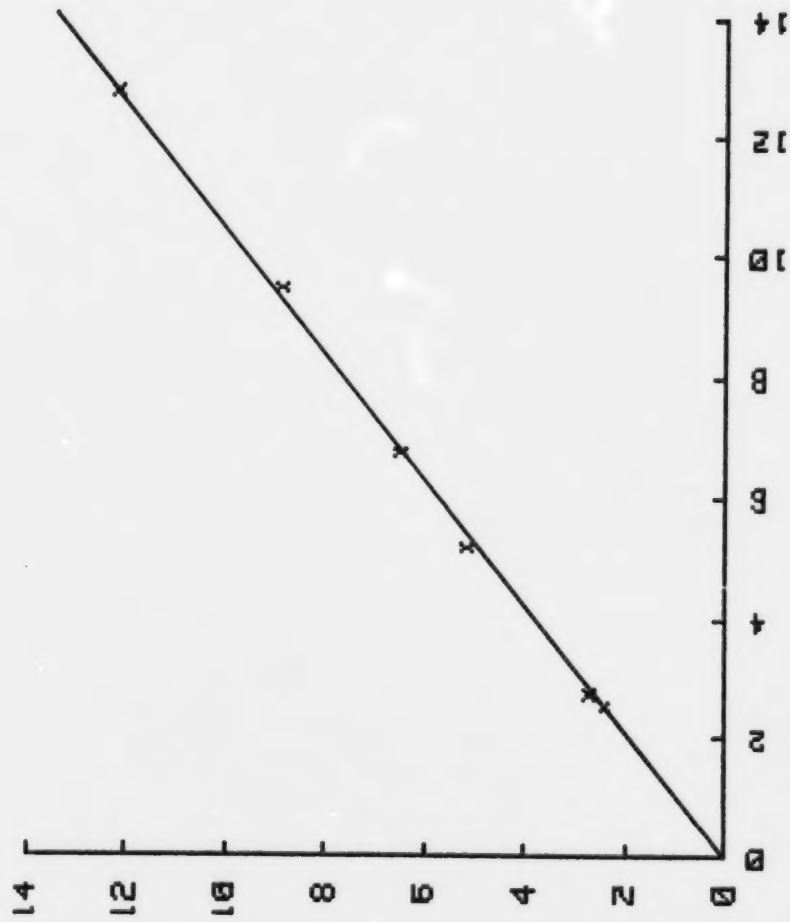
CAL RIG HYSTERESIS AT Alpha=26 Theta=55



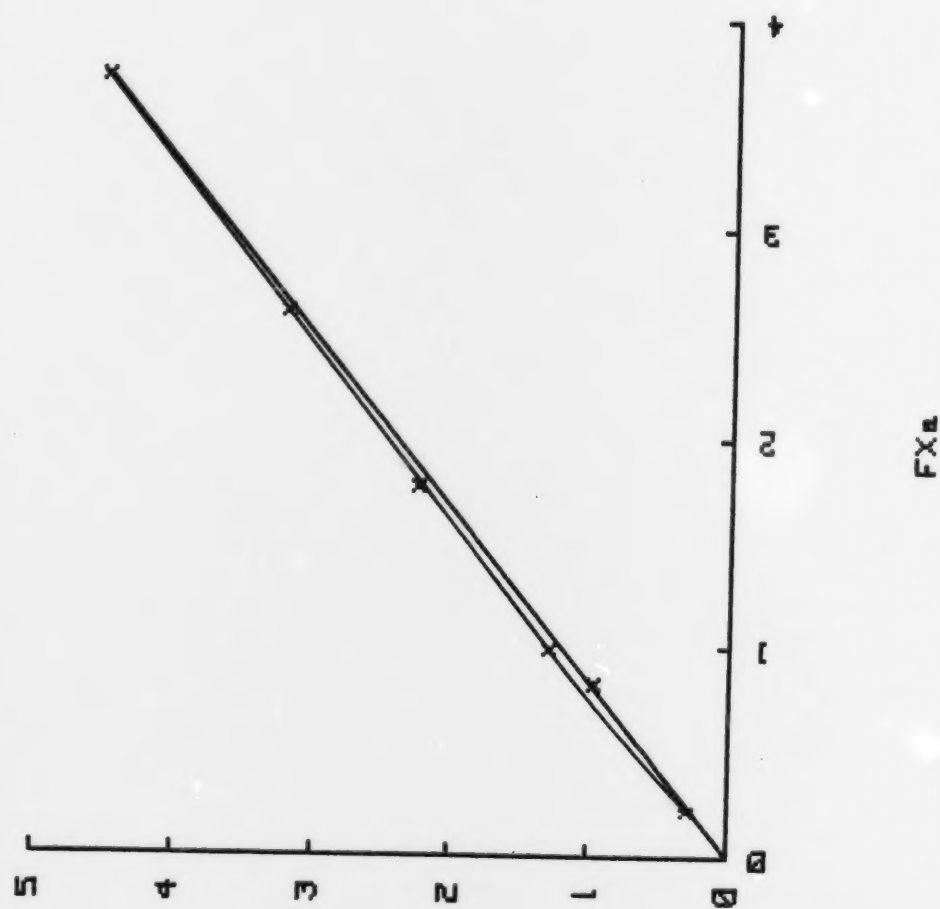
CAL RIG HYSTERESIS AT $\alpha = 26$ $\theta = 55$



CAL RIG HYSTERESIS AT Alpha=26 Theta=55



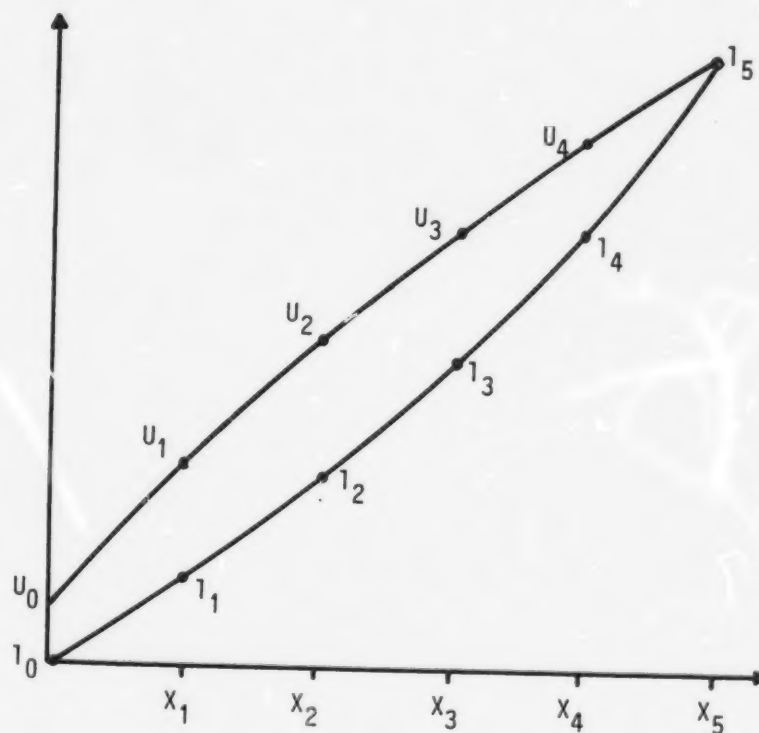
CAL RIG HYSTERESIS AT $\alpha = 26$ $\theta = 55$



APPENDIX F

DEFINITIONS OF TRANSDUCER ZERO STABILITY, LINEARITY AND HYSTERESIS

DEFINITIONS OF ZERO STABILITY, LINEARITY AND HYSTERESIS



$$\text{Zero Stability} = \left| \frac{I_0 - U_0}{I_5 - U_5} \right| \times 100\%$$

$$\text{Linearity} = \text{Maximum of } \frac{I_1 - I_0}{I_5 - I_0} - \frac{x_1}{x_5}, \frac{I_2 - I_0}{I_5 - I_0} - \frac{x_2}{x_5}, \text{ etc.}$$

$$\text{Hysteresis} = \text{Maximum of } \frac{I_1 - U_1}{I_5 - I_0} \times 100\%, \frac{I_2 - U_2}{I_5 - I_0} \times 100\%, \text{ etc.}$$

APPENDIX G

PRELIMINARY CALIBRATIONS OF SEGMENT 2

APPENDIX G.1

RESULTS OF PRELIMINARY INTERNAL CALIBRATIONS
ON SEGMENT 2 (BEFORE FINAL MODIFICATIONS)

G.1 Preliminary Segment 2 Internal Calibrations

In order to determine the response of Segment 2 to loads applied along the X, Y and Z axis, (pure longitudinal, horizontal and vertical loads) a calibration was carried out using the respective tension links to apply the load. The response of the compression load cells could then be observed. In this calibration, ideally only those load cells recording loads in the direction of the applied load should record significant loading.

The procedure for carrying out this calibration was to leave the tension links normal to the direction of applied force at their correct preloads, and to increase and decrease the preload on the remaining tension link. The tensioning calibrations were performed with the model in the water.

The results of this calibration are summarized in Table G.1. The measured horizontal load was between 0.94 and 0.97 of that applied. The error measured during longitudinal loading ranged from 7.5 to 16 percent. During longitudinal loading, a vertical load (positive z direction) of about 7% of the applied longitudinal load was measured. The load measured by the vertical load cells during loading by the vertical tension link was consistently about 12% greater than that applied. No coupling was recorded during the vertical loading.

Since there are 4 transducers in the vertical direction it was possible to determine the location of what appeared to be an additional force. Using the data from the 66.1N applied load and the 93.8N applied load, the location of the error force was found. In one case the x, y coordinates of the point were (.160, .289) and in the other (.165, .285). Since the coordinates of the point were consistent with both loads it was decided to correct the error. As can be seen in Figure G.1 this point is on a straight line between V_{22} and V_{23} indicating that the error was probably a combination of error in V_{22} and V_{23} with very little error occurring in V_{25} , V_{26} and V_{21} . If perhaps the error in measurement had been a result of the tension link V_{25} measuring the applied load incorrectly the error would have located at or close to V_{25} . It was calculated that multiplying V_{22} by .86 and V_{23} by .78 this force could be removed and the sum of the moments in the x and y directions would be nearly zero. Therefore these two correction factors have been put in place on the two transducers.

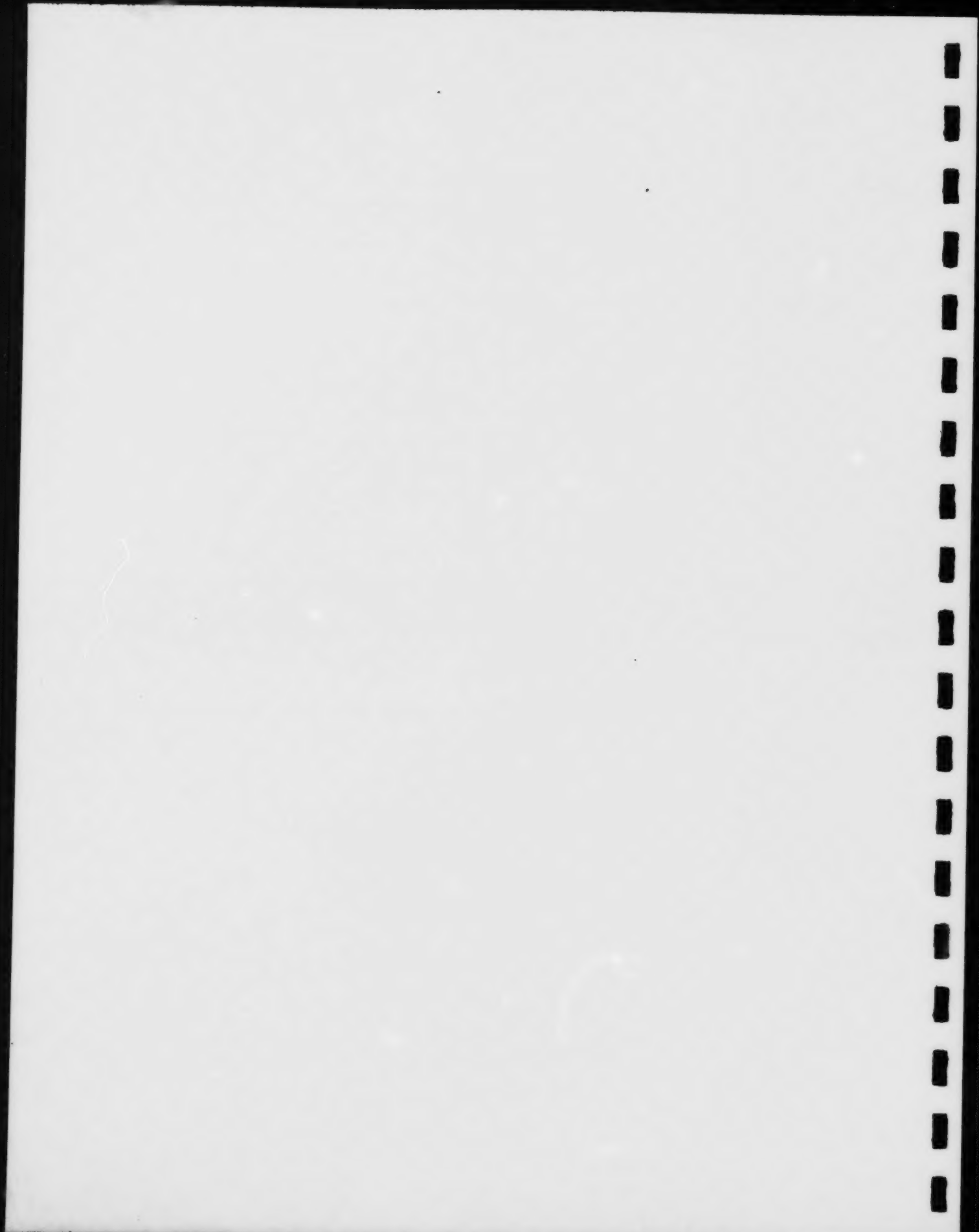


TABLE G.1

SEGMENT 2: PRELIMINARY TENSIONING CALIBRATION

VERTICAL TENSIONING

Applied Load, N	14.0	20.6	30.6	45.1	47.4	66.1	73.8	93.8	*A.R.R.
<u>longitudinal response</u> <u>applied vertical load</u>	-0.01	-.03	0.0	-.01	0.0	.01	-0.2	-.01	-0.01
<u>horizontal response</u> <u>applied vertical load</u>	+0.05	-0.06	0.03	-.04	.04	0.03	-.03	-.04	0.00
<u>vertical response</u> <u>applied vertical load</u>	1.12	1.14	1.14	1.14	1.13	1.14	1.14	1.14	1.14

HORIZONTAL TENSIONING

Applied Load, N	19.6	20.0	32.2	38.2	40.7	56.6	76.5	97.8	110.5	A.R.R.
<u>longitudinal response</u> <u>applied horizontal load</u>	-.01	0	0	0	0	0	0	0	.01	0.00
<u>horizontal response</u> <u>applied vertical load</u>	.94	0.95	0.95	0.95	0.95	0.95	0.97	0.97	0.96	0.95
<u>vertical response</u> <u>applied vertical load</u>	.02	0.03	0.01	-.02	0.01	-.02	-.02	-.02	-.02	0.00

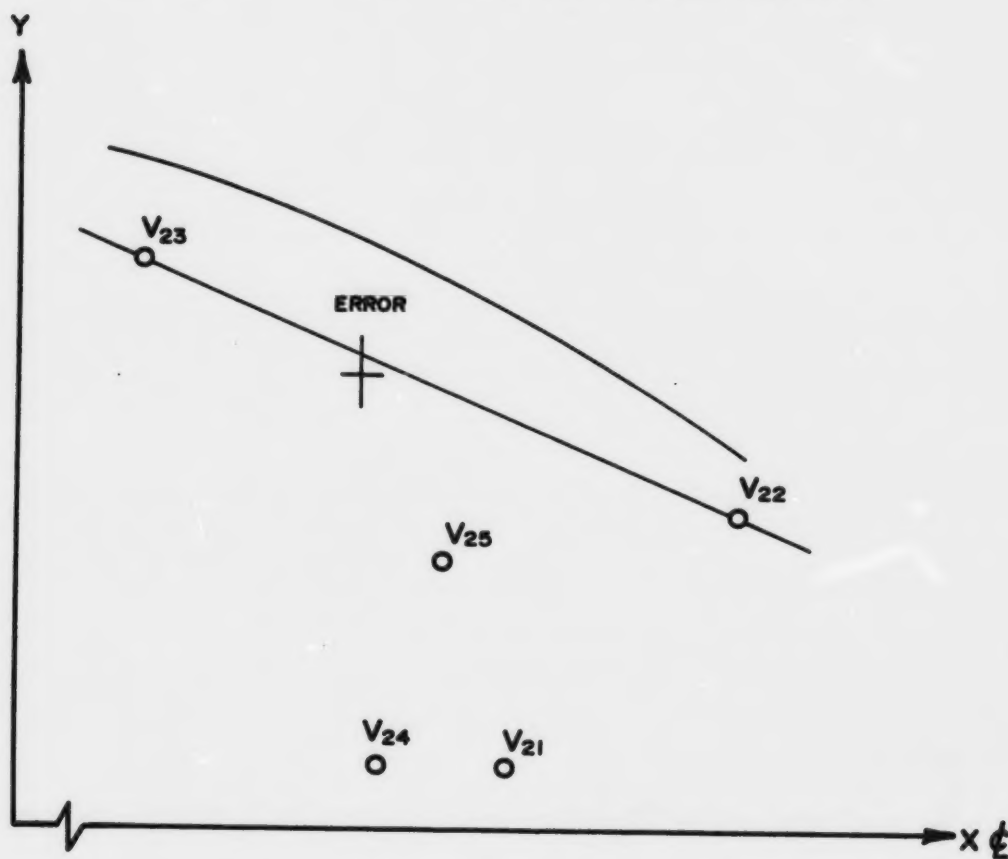
LONGITUDINAL TENSIONING

Applied Load, N	4.4	10.4	11.6	13.4	16.5	27.3	27.4	31.2	36.5	49.0	A.R.R.
<u>longitudinal response</u> <u>applied longitudinal load</u>	.87	0.84	0.90	1.00	0.87	0.96	0.91	0.96	0.92	0.91	.91
<u>horizontal response</u> <u>applied longitudinal load</u>	.03	0.01	-.01	.02	.01	.01	.01	.0	.01	-.01	.01
<u>vertical response</u> <u>applied longitudinal load</u>	.04	0.07	.07	.09	.06	.07	.06	.06	.08	.07	.06

*A.R.R. = Average Response Ratio

Figure G.1

**SEGMENT 2 TRANSDUCER POSITIONS
and TENSIONING CALIBRATION ERROR POSITION**



Scale 1mm : 4mm

**G.2 SEGMENT 2 PRELIMINARY CALIBRATION RESULT (FROM CALIBRATIONS
BEFORE REMOVAL OF VERTICAL TRANSDUCER V_{24} AND WITH TENSIONING
CALIBRATION CORRECTION FACTORS)**

This appendix contains Table G.2 which is a summary table of the uncorrected preliminary Segment 2 calibrations and the calibration result sheets from the external calibration. The result sheets are listed in order of increasing calibration point number. These calibrations were performed before the final modifications to segment 2. The measurements of transducers V_{23} and V_{24} have been pre-multiplied by 0.86 and 0.78 respectively. These two numbers were derived from the internal calibrations discussed in Appendix G.1.

The procedure for the external calibration and an explanation of the calibration result sheet are given in Section 4, Volume I.

The number in the file name of the calibration indicates the calibration point on the segment. A file name beginning with a "W" indicates an "in-water" calibration whereas one without indicates an "in-air" calibration.

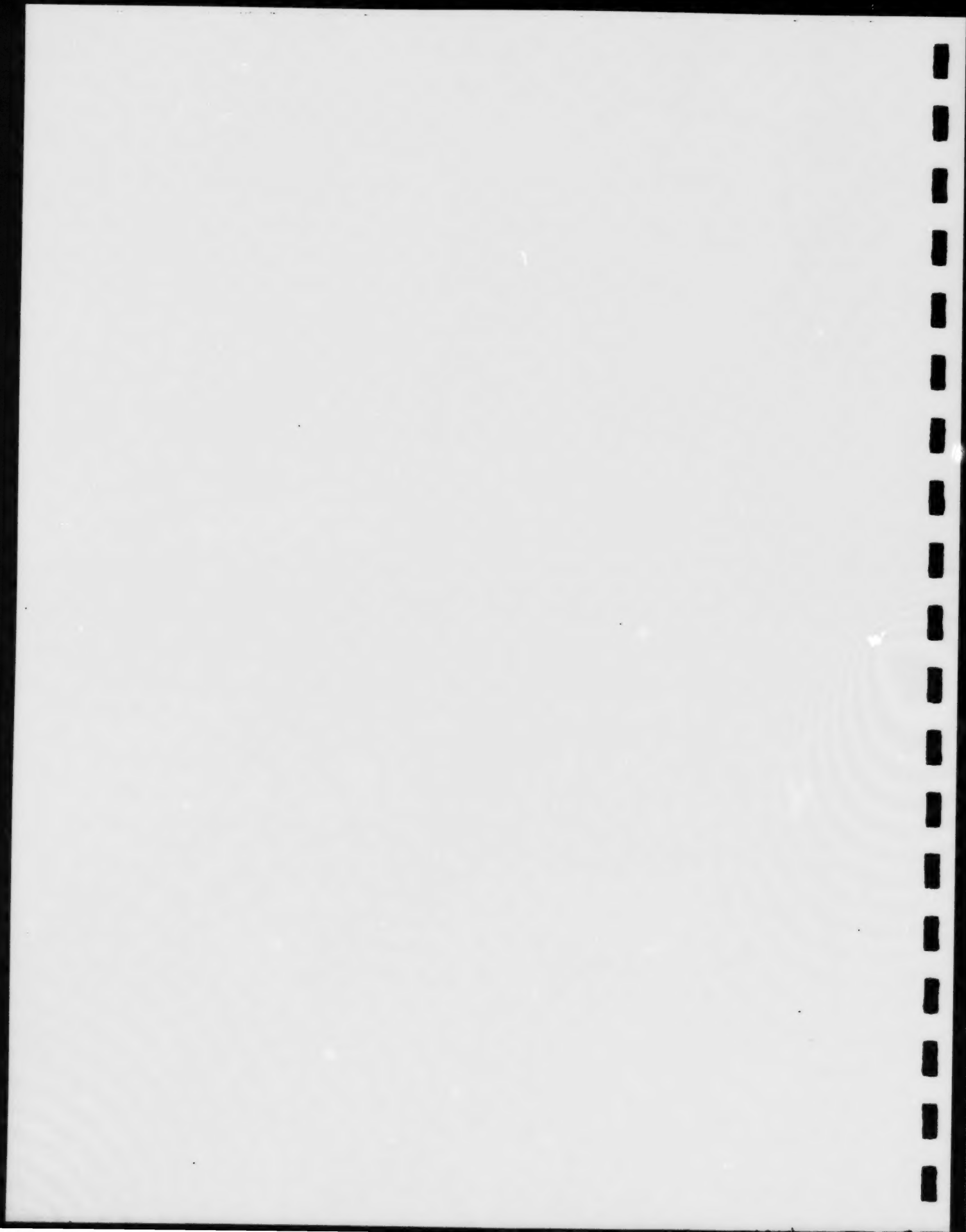


Table G.2 Summary of Uncorrected Preliminary Segment 2 Calibrations

Calibration Position	Air or Water (A/W)	Total applied Force Newtons	% error in Fx	Error in Fx Newtons	% error in Fy	Error in Fy Newtons	% error in Fz	Error in Fz Newtons
1	A	81.4	-47	-13.5	1	0.5	-14	-7.8
1*	W	55.0	-53	-17.2	16	4.8	-26	-8.3
2	A	76.8	-45	-12.7	3	1.5	-16	-8.9
2	W	79.9	-26	-8.3	3	1.4	-14	-7.2
3	A	79.9	-40	-12.3	5	2.1	-20	-12.2
3*	W	76.7	6	1.4	-6	-2.5	-14	-8.3
4	A	84.7	-67	-19.2	11	6.1	-14	-8.0
4*	W	93.6	-32	-7.2	5	2.8	-25	-14.4
5	A	68.1	-64	-14.8	-6	-2.2	-19	-9.5
5	W	79.5	-24	-6.2	-8	-4.6	-11	-5.4
6*	A	96.3	-38	-10.4	20	7.65	-23	-19.3
6*	W	84.6	-8	-1.9	-15	-6.7	-16	-10.8
7	A	96.1	-39	-14.4	4	1.3	-24	-17.7
7	W	78.0	-29	-10.5	10	3.8	-13	-7.4
8	A	80.4	-42	-13.6	2	0.9	-23	-13.5
8	W	84.5	-34	-10.6	2	0.9	-11	-7.1
9	A	67.4	-48	-11.0	16	5.2	-22	-11.9
9	W	79.4	-43	-13.2	6	2.7	-26	-15.1
10	A	82.0	-39	-11.8	7	3.1	-24	-14.8
10	W	84.5	-30	-11.7	21	8.6	-23	-14.4
11	A	32.4	-25	-3.4	7	1.3	-19	-4.4
11	W	43.3	-42	-6.1	29	4.8	-23	-8.5
12*	A	86.2	-50	-10.0	31	9.2	-21	-16.5
12	W	68.4	-58	-11.8	21	8.5	-19	-9.7
13	A	59.1	-20	-4.3	21	6.0	-21	-9.9
13	W	68.4	-58	-12.6	20	6.3	-14	-7.9
14*	A	49.8	-21	-3.2	30	4.8	-20	-8.9
14	W	63.0	-44	-11.7	-1	-3.3	-20	-9.4
15*	A	74.9	12	1.9	35	5.6	-19	-13.6
15*	W	70.4	-30	-5.1	15	2.2	-28	-18.7
OVERALL	Maximum	96.3	-20	-3.4	29	8.6	-26	-4.4
	Minimum	32.4	-67	-14.4	-8	-4.6	-11	-17.7
	Mean	73.2	-41	-11.1	8	2.6	-19	-10.0
	Stand. Dev.	14.6	13	3.7	10	3.6	5	3.5
Above 22' WL Mean			-42		2		-17	
Stand Dev			14		5		5	
Below 22' WL Mean			-41		14		-23	
Stand Dev			13		10		4	

* indicates that the calibration result was not used in the statistical analysis

Table G.2 Summary of Uncorrected Preliminary Segment 2 Calibrations

Calibration Position	Air or Water (A/W)	% error in Normal Force	Error in Normal Force Newtons	% error in Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm
1	A	-10	-7.9	-26	-5.2	21	0
1*	W	-12	-6.1	-98	-19.3	43	8
2	A	-11	-8.2	-29	-5.1	19	-11
2	W	-7	-5.7	-75	-8.2	12	5
3	A	-14	-10.9	-28	-5.1	18	-11
3*	W	-8	-6.2	-34	-5.8	-15	7
4	A	-6	-5.1	-25	-6.5	26	6
4*	W	-7	-6.0	-59	-21.7	32	43
5	A	-18	-11.7	-16	-3.3	24	-10
5	W	-10	-7.9	-47	-4.6	35	12
6*	A	-10	-8.7	-43	-18.0	11	0
6*	W	-14	-11.3	-25	-6.3	16	10
7	A	-16	-15.5	-39	-6.4	20	-18
7	W	-8	-6.2	-59	-10.3	-20	5
8	A	-17	-13.7	-5	-0.4	21	-20
8	W	-10	-8.3	-16	-2.0	-17	4
9	A	-11	-7.0	-42	-8.8	23	-12
9	W	-15	-11.6	-62	-10.7	43	-2
10	A	-15	-12.1	-32	-4.2	1	-9
10	W	-9	-7.4	-94	-17.5	10	-1
11	A	-11	-3.6	113	1.6	-6	-7
11	W	-14	-5.7	-46	-5.0	20	-13
12*	A	-8	-6.0	-40	-16.6	29	0
12	W	-6	-4.0	5	0.7	50	1
13	A	-8	-4.7	-62	-5.6	20	0
13	W	-9	-6.2	8	1.0	21	3
14*	A	-10	-4.9	-46	-7.6	4	6
14	W	-18	-11.3	21	1.0	37	-42
15*	A	-10	-6.7	-41	-12.9	-12	-3
15*	W	-23	-14.8	-40	-11.4	-8	-8
OVERALL	Maximum	-6	-3.6	113		50	5
	Minimum	-18	-15.5	-94	-17.5	-20	-42
	Mean	-12	-8.3	-26	-5.0	18	-6
	Stand. Dev.	4	3.3	43	4.7	17	12

* indicates that the calibration result was not used in the statistical analysis

SEGMENT NUMBER 2 FILE NAME POS_1
 AUG 2 CALIBRATION POSITION POS 1

TRANSDUCER	READING (N)
R-21	13.41
R-22	1.98
H-21	2.80
H-22	45.39
H-23	4.17
V-21	-10.54
V-22	30.46
V-23	38.87
V-24	-12.62
V-25	1.62
T'V	19.37
T'L	-6.39
NOR	78.80

	APPLIED	MEASURED	% ERROR
FORCES IN X	28.91	15.39	-47.
Y	51.76	52.36	1.
Z	55.77	47.80	-14.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -14.50 X PLANE
 C2= 8.45 Y PLANE
 C3= -2.76 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.759	1.780	.021 m
Z=	.011	.011	0.000 m
WATERPLANE ANGLE	23.	23.	0. DEG
FLARE ANGLE	32.	33.	1. DEG
TOTAL FORCE	81.395	72.547	-10.9 %
NORMAL FORCE	78.797	70.937	-10.0 %
FRICTION FACTOR	.259	.214	
FRICTION FORCE	20.399	15.202	-25.5 %
FRICTION DIRECTION	72.	116.	44. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME WPOS_1
 AUG 29 CALIBRATION POSITION WPOS1

TRANSDUCER	READING (N)
R-21	14.58
R-22	.89
H-21	-2.16
H-22	34.48
H-23	2.88
V-21	-8.69
V-22	18.96
V-23	17.36
V-24	-4.26
V-25	.37
T'V	7.74
T'L	-18.15
NOR	51.29

	APPLIED	MEASURED	% ERROR
FORCES IN X	32.64	15.48	-53.
Y	30.44	35.20	16.
Z	32.07	23.74	-26.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -6.48 X PLANE
 C2= 4.50 Y PLANE
 C3= .21 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.759	1.802	.043 m
Z=	.011	.019	.008 m
WATERPLANE ANGLE	23.	24.	1. DEG
FLARE ANGLE	32.	35.	3. DEG
TOTAL FORCE	54.955	45.191	-17.8 %
NORMAL FORCE	51.292	45.189	-11.9 %
FRICTION FACTOR	.385	.009	
FRICTION FORCE	19.728	.425	-97.8 %
FRICTION DIRECTION	23.	-29.	-52. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME POS_2
 AUG 22 CALIBRATION POSITION POS 2

TRANSDUCER	READING (N)
R-21	13.20
R-22	2.28
H-21	17.86
H-22	24.45
H-23	4.27
V-21	-10.26
V-22	45.65
V-23	24.87
V-24	-15.57
V-25	1.87
T'V	16.23
T'L	-6.85
NOR	74.78

		APPLIED	MEASURED	% ERROR
FORCES IN	X	28.25	15.48	-45.
	Y	45.04	46.58	3.
	Z	55.45	46.57	-16.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -13.03 X PLANE
 C2= 13.41 Y PLANE
 C3= -7.77 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.888	.019 m
Z=	.011	0.000	-.011 m
WATERPLANE ANGLE	25.	24.	-1. DEG
FLARE ANGLE	37.	36.	-1. DEG
TOTAL FORCE	76.823	67.660	-11.9 %
NORMAL FORCE	74.777	66.503	-11.1 %
FRICTION FACTOR	.236	.187	
FRICTION FORCE	17.614	12.464	-29.2 %
FRICTION DIRECTION	67.	111.	44. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME WPOS_2
 AUG 29 CALIBRATION POSITION WPOS_2

TRANSDUCER	READING (N)
R-21	22.14
R-22	1.54
H-21	15.96
H-22	33.22
H-23	4.47
V-21	-19.23
V-22	44.57
V-23	20.93
V-24	-2.46
V-25	.50
T'V	8.26
T'L	-7.19
NOR	79.13

FORCES IN		APPLIED	MEASURED	% ERROR
X		31.94	23.68	-26.
Y		52.24	53.65	3.
Z		51.31	44.31	-14.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -10.95 X PLANE
 C2= 12.06 Y PLANE
 C3= -6.48 Z PLANE

LOCATION		APPLIED	MEASURED	ERROR
:X=		1.869	1.881	.012 m
Z=		.011	.017	.005 m
WATERPLANE ANGLE	25.		25.	1. DEG
FLARE ANGLE	37.		38.	1. DEG
TOTAL FORCE	79.883		73.503	-8.0 %
NORMAL FORCE	79.129		73.452	-7.2 %
FRICTION FACTOR	.138		.037	
FRICTION FORCE	10.951		2.727	-75.1 %
FRICTION DIRECTION	49.		121.	73. DEG
FROM THE HORIZONTAL				

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SEGMENT NUMBER 2 FILE NAME POS_3
 AUG 22 CALIBRATION POSITION POS 3

TRANSDUCER READING (N)

R-21	15.27
R-22	3.37
H-21	33.46
H-22	7.11
H-23	2.98
V-21	-8.23
V-22	62.77
V-23	10.28
V-24	-16.77
V-25	1.00
T'V	16.74
T'L	-7.99
NOR	77.75

		APPLIED	MEASURED	% ERROR
FORCES IN	X	30.93	18.65	-40.
	Y	41.35	43.55	5.
	Z	61.06	49.06	-20.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -11.50 X PLANE
 C2= 19.48 Y PLANE
 C3= -12.54 Z PLANE

		APPLIED	MEASURED	ERROR
LOCATION	:X=	1.979	1.997	.018 m
	Z=	.011	0.000	-.011 m
WATERPLANE ANGLE		28.	28.	0. DEG
FLARE ANGLE		41.	39.	-3. DEG
TOTAL FORCE		79.931	68.197	-14.7 %
NORMAL FORCE		77.749	66.857	-14.0 %
FRICTION FACTOR		.239	.201	
FRICTION FORCE		18.550	13.453	-27.5 %
FRICTION DIRECTION		64.	108.	44. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME WPOS_3
 AUG 29 CALIBRATION POSITION WPOS_3

TRANSDUCER	READING (N)
R-21	23.68
R-22	1.98
H-21	29.49
H-22	7.50
H-23	2.73
V-21	-15.44
V-22	58.52
V-23	9.08
V-24	-1.36
V-25	.25
T'V	17.07
T'L	-1.71
NOR	74.80

FORCES IN		APPLIED	MEASURED	% ERROR
X		24.10	25.67	6.
Y		42.04	39.72	-6.
Z		59.50	51.05	-14.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-10.75	X PLANE
C2=	18.14	Y PLANE
C3=	-9.96	Z PLANE

LOCATION		APPLIED	MEASURED	ERROR
:X=		1.979	1.964	-.015 m
Z=		.011	.018	.007 m
WATERPLANE ANGLE		28.	28.	-0. DEG
FLARE ANGLE		41.	42.	1. DEG
TOTAL FORCE		76.739	69.593	-9.3 %
NORMAL FORCE		74.797	68.672	-8.2 %
FRICTION FACTOR		.229	.164	
FRICTION FORCE		17.158	11.287	-34.2 %
FRICTION DIRECTION		84.	68.	-17. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME POS_4
 AUG 22 CALIBRATION POSITION POS 4

TRANSDUCER	READING (N)
R-21	8.78
R-22	.79
H-21	-13.08
H-22	71.70
H-23	2.98
V-21	-8.64
V-22	8.10
V-23	55.43
V-24	-6.52
V-25	.87
T'V	24.19
T'L	-9.24
NOR	80.69

	APPLIED	MEASURED	% ERROR
FORCES IN X	28.70	9.57	-67.
Y	55.63	61.60	11.
Z	57.11	49.23	-14.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-15.36	X PLANE
C2=	2.18	Y PLANE
C3=	1.91	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.625	1.651	.026 m
Z=	.027	.033	.006 m
WATERPLANE ANGLE	19.	20.	1. DEG
FLARE ANGLE	27.	29.	2. DEG
TOTAL FORCE	84.740	79.434	-6.3 %
NORMAL FORCE	80.686	77.005	-4.6 %
FRICTION FACTOR	.321	.253	
FRICTION FORCE	25.897	19.493	-24.7 %
FRICTION DIRECTION	69.	128.	59. DEG
FROM THE HORIZONTAL			

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SEGMENT NUMBER 2 FILE NAME WPOS_4
 AUG 29 CALIBRATION POSITION WPOS_4

TRANSDUCER	READING (N)
R-21	14.75
R-22	.69
H-21	-17.59
H-22	74.13
H-23	3.38
V-21	1.48
V-22	-.88
V-23	51.71
V-24	-.04
V-25	.75
T'V	36.73
T'L	-2.97
NOR	86.11

FORCES IN	X	APPLIED	MEASURED	% ERROR
	X	22.56	15.44	-32.
	Y	57.07	59.92	5.
	Z	70.76	53.02	-25.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-13.17	X PLANE
C2=	1.94	Y PLANE
C3=	4.24	Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.625	1.657	.032 m
	Z=	.027	.070	.043 m
WATERPLANE ANGLE		19.	22.	3. DEG
FLARE ANGLE		27.	34.	7. DEG
TOTAL FORCE		93.663	81.487	-13.0 %
NORMAL FORCE		86.110	80.069	-7.0 %
FRICTION FACTOR		.428	.189	
FRICTION FORCE		36.850	15.135	-58.9 %
FRICTION DIRECTION		85.	124.	38. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME POS_5
 AUG 22 CALIBRATION POSITION POS_5

TRANSDUCER	READING (N)
R-21	7.19
R-22	.99
H-21	5.41
H-22	28.64
H-23	2.98
V-21	-7.30
V-22	23.41
V-23	31.80
V-24	-8.44
V-25	1.62
T'V	20.05
T'L	-5.93
NOR	64.80

	APPLIED	MEASURED	% ERROR
FORCES IN X	23.03	8.18	-64.
Y	39.26	37.03	-6.
Z	50.64	41.09	-19.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-12.17	X PLANE
C2=	7.37	Y PLANE
C3=	-3.47	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.759	1.783	.024 m
Z=	.027	.017	-.010 m
WATERPLANE ANGLE	23.	23.	1. DEG
FLARE ANGLE	33.	33.	0. DEG
TOTAL FORCE	68.092	55.912	-17.9 %
NORMAL FORCE	64.802	53.097	-18.1 %
FRICTION FACTOR	.323	.330	
FRICTION FORCE	20.911	17.520	-16.2 %
FRICTION DIRECTION	74.	114.	41. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME WPOS_5
AUG 29 CALIBRATION POSITION WPOS_5

TRANSDUCER	READING (N)
R-21	18.65
R-22	1.09
H-21	-1.04
H-22	49.29
H-23	4.37
V-21	-12.39
V-22	26.13
V-23	29.03
V-24	0.00
V-25	.62
T'V	9.50
T'L	-1.71
NOR	78.96

FORCES IN	X	APPLIED	MEASURED	% ERROR
	X	25.98	19.74	-24.
	Y	57.09	52.62	-8.
	Z	48.92	43.40	-11.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-10.61	X PLANE
C2=	7.63	Y PLANE
C3=	-.88	Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.759	1.794	.035 m
	Z=	.027	.039	.012 m
WATERPLANE ANGLE		23.	23.	0. DEG
FLARE ANGLE		33.	36.	3. DEG
TOTAL FORCE		79.549	71.008	-10.7 %
NORMAL FORCE		78.961	70.827	-10.3 %
FRICTION FACTOR		.122	.072	
FRICTION FORCE		9.657	5.072	-47.5 %
FRICTION DIRECTION		80.	119.	39. DEG
FROM THE HORIZONTAL				

ARCTEC CANADA LTD.

PROJECT 1566C

AUG 22 SEGMENT NUMBER 2 FILE NAME POS_6
 CALIBRATION POSITION POS 6

TRANSDUCER	READING (N)
R-21	14.42
R-22	2.68
H-21	17.50
H-22	24.06
H-23	4.47
V-21	-5.82
V-22	50.58
V-23	28.63
V-24	-10.96
V-25	2.56
T'V	41.01
T'L	-7.99
NOR	86.80

		APPLIED	MEASURED	% ERROR
FORCES IN	X	27.46	17.10	-38.
	Y	38.26	46.03	20.
	Z	84.03	64.99	-23.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-15.73	X PLANE
C2=	17.75	Y PLANE
C3=	-7.48	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.880	.011 m
Z=	.027	.027	-.000 m
WATERPLANE ANGLE	26.	26.	0. DEG
FLARE ANGLE	39.	39.	1. DEG
TOTAL FORCE	96.332	81.450	-15.4 %
NORMAL FORCE	86.802	77.835	-10.3 %
FRICTION FACTOR	.481	.308	
FRICTION FORCE	41.777	23.996	-42.6 %
FRICTION DIRECTION	79.	102.	23. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME WPOS_6
AUG 29 CALIBRATION POSITION WPOS_6

TRANSDUCER	READING (N)
R-21	20.19
R-22	1.49
H-21	11.09
H-22	23.18
H-23	3.82
V-21	-11.00
V-22	45.53
V-23	21.37
V-24	0.00
V-25	1.00
T'V	25.35
T'L	-1.60
NOR	80.71

	APPLIED	MEASURED	% ERROR
FORCES IN X	23.55	21.68	-8.
Y	44.85	38.10	-15.
Z	67.77	56.90	-16.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-12.84	X PLANE
C2=	15.41	Y PLANE
C3=	-4.06	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.885	.016 m
Z=	.027	.037	.010 m
WATERPLANE ANGLE	26.	29.	3. DEG
FLARE ANGLE	39.	41.	2. DEG
TOTAL FORCE	84.615	71.827	-15.1 %
NORMAL FORCE	80.713	69.243	-14.2 %
FRICTION FACTOR	.315	.276	
FRICTION FORCE	25.401	19.095	-24.8 %
FRICTION DIRECTION	86.	89.	3. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME POS_7
 AUG 25 CALIBRATION POSITION POS 7CORRECT

TRANSDUCER	READING (N)
R-21	18.52
R-22	3.97
H-21	39.59
H-22	9.94
H-23	3.68
V-21	-6.66
V-22	67.74
V-23	8.83
V-24	-15.72
V-25	.87
T'V	14.47
T'L	-7.76
NOR	94.67

	APPLIED	MEASURED	% ERROR
FORCES IN X	36.98	22.49	-39.
Y	50.93	53.20	4.
Z	72.59	55.06	-24.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -11.38 X PLANE
 C2= 21.77 Y PLANE
 C3= -14.90 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.979	1.999	.020 m
Z=	.027	.009	-.018 m
WATERPLANE ANGLE	29.	29.	-0. DEG
FLARE ANGLE	44.	42.	-3. DEG
TOTAL FORCE	96.080	79.800	-16.9 %
NORMAL FORCE	94.667	79.160	-16.4 %
FRICTION FACTOR	.173	.127	
FRICTION FORCE	16.417	10.086	-38.6 %
FRICTION DIRECTION FROM THE HORIZONTAL	62.	125.	63. DEG

SEGMENT NUMBER 2 FILE NAME WPOS_7
 AUG 29 CALIBRATION POSITION WPOS_7

TRANSDUCER	READING (N)
R-21	23.73
R-22	2.13
H-21	31.75
H-22	7.11
H-23	2.63
V-21	-10.36
V-22	52.51
V-23	7.95
V-24	.02
V-25	.25
T'V	10.89
T'L	-13.58
NOR	76.03

	APPLIED	MEASURED	% ERROR
FORCES IN X	36.36	25.86	-29.
Y	37.77	41.49	10.
Z	57.75	50.37	-13.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -9.39 X PLANE
 C2= 17.27 Y PLANE
 C3= -10.82 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.979	1.959	-.020 m
Z=	.027	.032	.005 m
WATERPLANE ANGLE	29.	29.	0. DEG
FLARE ANGLE	44.	44.	-0. DEG
TOTAL FORCE	78.000	70.193	-10.0 %
NORMAL FORCE	76.033	69.831	-8.2 %
FRICTION FACTOR	.229	.102	
FRICTION FORCE	17.407	7.125	-59.1 %
FRICTION DIRECTION	39.	71.	33. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME POS_8
 AUG 25 CALIBRATION POSITION POS 8

TRANSDUCER	READING (N)
R-21	15.48
R-22	3.27
H-21	39.95
H-22	2.87
H-23	2.38
V-21	-5.13
V-22	60.76
V-23	2.63
V-24	-13.20
V-25	.25
T'V	6.23
T'L	-6.16
NOR	79.87

		APPLIED	MEASURED	% ERROR
FORCES IN	X	32.39	18.75	-42.
	Y	44.35	45.21	2.
	Z	58.65	45.30	-23.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-8.60	X PLANE
C2=	19.62	Y PLANE
C3=	-14.79	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	2.015	2.036	.021 m
Z=	.027	.007	-.020 m
WATERPLANE ANGLE	30.	30.	-0. DEG
FLARE ANGLE	47.	42.	-5. DEG
TOTAL FORCE	80.351	66.693	-17.0 %
NORMAL FORCE	79.871	66.167	-17.2 %
FRICTION FACTOR	.110	.126	
FRICTION FORCE	8.765	8.362	-4.6 %
FRICTION DIRECTION	45.	136.	91. DEG
FROM THE HORIZONTAL			

ARCTEC CANADA LTD.

PROJECT 1566C

AUG 29 SEGMENT NUMBER 2 FILE NAME WPOS_8
 CALIBRATION POSITION WPOS_8

TRANSDUCER	READING (N)
R-21	18.97
R-22	1.78
H-21	38.87
H-22	3.30
H-23	2.29
V-21	-10.26
V-22	64.93
V-23	3.06
V-24	.04
V-25	0.00
T'V	11.34
T'L	-5.25
NOR	83.54

FORCES IN		APPLIED	MEASURED	% ERROR
X		31.23	20.76	-34.
Y		44.15	45.05	2.
Z		64.89	57.77	-11.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-9.82	X PLANE
C2=	22.35	Y PLANE
C3=	-14.05	Z PLANE

LOCATION		APPLIED	MEASURED	ERROR
:X=		2.015	1.998	-.017 m
Z=		.027	.031	.004 m
WATERPLANE ANGLE		30.	30.	0. DEG
FLARE ANGLE		47.	46.	-0. DEG
TOTAL FORCE		84.472	76.145	-9.9 %
NORMAL FORCE		83.543	75.416	-9.7 %
FRICTION FACTOR		.150	.139	
FRICTION FORCE		12.494	10.511	-15.9 %
FRICTION DIRECTION		65.	114.	49. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME POS_9
 AUG 22 CALIBRATION POSITION POS 9

TRANSDUCER	READING (N)
R-21	10.16
R-22	1.69
H-21	2.89
H-22	31.95
H-23	3.38
V-21	-1.57
V-22	16.11
V-23	26.73
V-24	-5.50
V-25	1.69
T'V	20.18
T'L	-6.39
NOR	64.02

		APPLIED	MEASURED	% ERROR
FORCES IN	X	22.89	11.84	-48.
	Y	32.99	38.21	16.
	Z	54.16	42.45	-22.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -9.56 X PLANE
 C2= 7.02 Y PLANE
 C3= -2.31 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.759	1.782	.023 m
Z=	.072	.050	-.012 m
WATERPLANE ANGLE	26.	25.	-1. DEG
FLARE ANGLE	39.	39.	-1. DEG
TOTAL FORCE	67.425	58.335	-13.5 %
NORMAL FORCE	64.016	57.014	-10.9 %
FRICTION FACTOR	.331	.216	
FRICTION FORCE	21.169	12.341	-41.7 %
FRICTION DIRECTION	72.	115.	43. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME WPOS_9
 AUG 29 CALIBRATION POSITION WPOS_9

TRANSDUCER	READING (N)
R-21	16.49
R-22	.99
H-21	-1.26
H-22	44.32
H-23	4.22
V-21	2.13
V-22	16.03
V-23	23.63
V-24	0.00
V-25	1.25
T'V	15.04
T'L	-8.33
NOR	77.51

FORCES IN	X	APPLIED	MEASURED	% ERROR
	X	30.66	17.49	-43.
	Y	44.71	47.28	6.
	Z	58.01	43.04	-26.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-7.95	X PLANE
C2=	7.46	Y PLANE
C3=	-0.76	Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.759	1.802	.043 m
	Z=	.072	.070	-.002 m
WATERPLANE ANGLE		26.	27.	1. DEG
FLARE ANGLE		39.	41.	2. DEG
TOTAL FORCE		79.395	66.285	-16.5 %
NORMAL FORCE		77.512	65.957	-14.9 %
FRICTION FACTOR		.222	.100	
FRICTION FORCE		17.189	6.584	-61.7 %
FRICTION DIRECTION		61.	148.	87. DEG
FROM THE HORIZONTAL				

ARCTEC CANADA LTD.

PROJECT 1566C

SEGMENT NUMBER 2 FILE NAME POS_10
AUG 25 CALIBRATION POSITION POS 10

TRANSDUCER	READING (N)
R-21	15.64
R-22	2.88
H-21	16.23
H-22	27.47
H-23	4.32
V-21	1.76
V-22	27.42
V-23	16.77
V-24	-1.08
V-25	1.75
T'V	12.44
T'L	-4.34
NOR	80.90

	APPLIED	MEASURED	% ERROR
FORCES IN X	30.23	18.52	-39.
Y	44.81	48.03	7.
Z	61.62	46.61	-24.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-7.83	X PLANE
C2=	11.44	Y PLANE
C3=	-6.95	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.870	.001 m
Z=	.072	.063	-.009 m
WATERPLANE ANGLE	29.	30.	1. DEG
FLARE ANGLE	44.	43.	-1. DEG
TOTAL FORCE	81.969	69.440	-15.3 %
NORMAL FORCE	80.904	68.864	-14.9 %
FRICTION FACTOR	.163	.130	
FRICTION FORCE	13.170	8.925	-32.2 %
FRICTION DIRECTION	71.	152.	81. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME WPOS_10
 AUG 29 CALIBRATION POSITION WPOS_10

TRANSDUCER	READING (N)
R-21	25.17
R-22	1.98
H-21	18.49
H-22	27.32
H-23	3.97
V-21	5.27
V-22	26.81
V-23	15.17
V-24	0.00
V-25	1.25
T'V	12.59
T'L	-13.81
NOR	82.39

FORCES IN		APPLIED	MEASURED	% ERROR
X		38.99	27.15	-30.
Y		41.06	49.79	21.
Z		62.70	48.50	-23.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-7.16	X PLANE
C2=	11.60	Y PLANE
C3=	-6.67	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.879	.010 m
Z=	.072	.071	-.001 m
WATERPLANE ANGLE	29.	30.	0. DEG
FLARE ANGLE	44.	45.	0. DEG
TOTAL FORCE	84.480	74.622	-11.7 %
NORMAL FORCE	82.388	74.612	-9.4 %
FRICTION FACTOR	.227	.016	
FRICTION FORCE	18.685	1.210	-93.5 %
FRICTION DIRECTION	42.	175.	133. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME POS_11
 AUG 26 CALIBRATION POSITION POS 11

TRANSDUCER	READING (N)
R-21	8.21
R-22	1.98
H-21	16.59
H-22	2.44
H-23	.60
V-21	3.00
V-22	15.15
V-23	.58
V-24	-.31
V-25	.25
T'V	-.07
T'L	-1.37
NOR	32.36

FORCES IN	X	APPLIED	MEASURED	% ERROR
	X	13.53	10.19	-25.
	Y	18.32	19.63	7.
	Z	23.03	18.68	-19.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-1.89	X PLANE
C2=	6.31	Y PLANE
C3=	-5.85	Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.979	1.973	-.006 m
	Z=	.072	.065	-.007 m
WATERPLANE ANGLE		33.	32.	-1. DEG
FLARE ANGLE		51.	49.	-1. DEG
TOTAL FORCE		32.391	28.946	-10.6 %
NORMAL FORCE		32.362	28.799	-11.0 %
FRICTION FACTOR		.042	.101	
FRICTION FORCE		1.371	2.917	112.7 %
FRICTION DIRECTION		-3.	-41.	-38. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME WPOS_11
 SEPT 5 CALIBRATION POSITION WPOS_11

TRANSDUCER	READING (N)
R-21	7.60
R-22	.89
H-21	18.40
H-22	2.73
H-23	.40
V-21	4.90
V-22	25.49
V-23	-.88
V-24	-1.32
V-25	.31
T'V	10.36
T'L	-3.20
NOR	41.88

FORCES IN		APPLIED	MEASURED	% ERROR
X		14.64	8.49	-42.
Y		16.68	21.52	29.
Z		37.13	28.51	-23.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-3.25	X PLANE
C2=	10.86	Y PLANE
C3=	-6.70	Z PLANE

LOCATION		APPLIED	MEASURED	ERROR
:X=		1.979	1.999	.020 m
Z=		.072	.059	-.013 m
WATERPLANE ANGLE		33.	32.	-1. DEG
FLARE ANGLE		51.	50.	-0. DEG
TOTAL FORCE		43.261	36.719	-15.1 %
NORMAL FORCE		41.881	36.247	-13.5 %
FRICTION FACTOR		.259	.162	
FRICTION FORCE		10.841	5.865	-45.9 %
FRICTION DIRECTION		73.	138.	65. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME POS_12
 AUG 26 CALIBRATION POSITION POS 12

TRANSDUCER	READING (N)
R-21	8.49
R-22	1.64
H-21	-10.37
H-22	47.44
H-23	1.94
V-21	5.78
V-22	-13.95
V-23	49.30
V-24	19.05
V-25	1.87
T'V	41.02
T'L	-5.93
NOR	75.55

FORCES IN	X	APPLIED	MEASURED	% ERROR
	X	20.07	10.13	-50.
	Y	29.73	39.01	31.
	Z	78.35	62.06	-21.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-12.53	X PLANE
C2=	1.99	Y PLANE
C3=	2.37	Z PLANE

LOCATION	:X=	APPLIED	MEASURED	ERROR
		1.625	1.654	.029 m
	Z=	.133	.133	0.000 m
WATERPLANE ANGLE		24.	26.	1. DEG
FLARE ANGLE		40.	42.	2. DEG
TOTAL FORCE		86.175	73.994	-14.1 %
NORMAL FORCE		75.554	69.700	-7.7 %
FRICTION FACTOR		.549	.356	
FRICTION FORCE		41.446	24.839	-40.1 %
FRICTION DIRECTION		82.	108.	27. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME WPOS_12
 SEPT 5 CALIBRATION POSITION WPOS_12

TRANSDUCER	READING (N)
R-21	8.13
R-22	.50
H-21	-15.06
H-22	60.88
H-23	3.18
V-21	9.06
V-22	-10.90
V-23	27.79
V-24	16.57
V-25	-1.12
T'V	13.55
T'L	-1.83
NOR	67.02

FORCES IN		APPLIED	MEASURED	% ERROR
X		20.40	8.62	-58.
Y		40.36	49.00	21.
Z		51.31	41.40	-19.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-4.68	X PLANE
C2=	1.93	Y PLANE
C3=	3.14	Z PLANE

LOCATION		APPLIED	MEASURED	ERROR
:X=		1.625	1.675	.050 m
Z=		.133	.134	.001 m
WATERPLANE ANGLE		24.	27.	2. DEG
FLARE ANGLE		40.	43.	4. DEG
TOTAL FORCE		68.398	64.722	-5.4 %
NORMAL FORCE		67.018	63.099	-5.8 %
FRICTION FACTOR		.204	.228	
FRICTION FORCE		13.670	14.404	5.4 %
FRICTION DIRECTION		82.	176.	94. DEG
FROM THE HORIZONTAL				

AUG 26 SEGMENT NUMBER 2 FILE NAME POS_13
 CALIBRATION POSITION POS_13

TRANSDUCER	READING (N)
R-21	14.22
R-22	2.97
H-21	3.07
H-22	28.83
H-23	2.78
V-21	8.69
V-22	-1.52
V-23	14.92
V-24	14.02
V-25	1.12
T'V	8.25
T'L	-3.88
NOR	58.41

		APPLIED	MEASURED	% ERROR
FORCES IN	X	21.52	17.19	-20.
	Y	28.76	34.68	21.
	Z	46.95	37.22	-21.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -3.43 X PLANE
 C2= 4.38 Y PLANE
 C3= -1.49 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.759	1.779	.020 m
	Z= .133	.133	0.000 m
WATERPLANE ANGLE	31.	31.	1. DEG
FLARE ANGLE	49.	49.	0. DEG
TOTAL FORCE	59.116	53.703	-9.2 %
NORMAL FORCE	58.408	53.589	-8.3 %
FRICTION FACTOR	.156	.065	
FRICTION FORCE	9.121	3.504	-61.6 %
FRICTION DIRECTION	65.	-80.	-145. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME WPOS_13
 SEPT 5 CALIBRATION POSITION WPOS_13

TRANSDUCER	READING (N)
R-21	8.57
R-22	.69
H-21	-1.71
H-22	36.04
H-23	3.58
V-21	11.83
V-22	1.36
V-23	18.45
V-24	15.84
V-25	1.44
T'V	13.34
T'L	-2.74
NOR	67.01

FORCES IN		APPLIED	MEASURED	% ERROR
X		21.83	9.27	-58.
Y		31.53	37.91	20.
Z		56.62	48.92	-14.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -5.16 X PLANE
 C2= 7.53 Y PLANE
 C3= -.97 Z PLANE

LOCATION		APPLIED	MEASURED	ERROR
:X=		1.759	1.780	.021 m
Z=		.133	.136	.003 m
WATERPLANE ANGLE	31.		32.	1. DEG
FLARE ANGLE	49.		50.	1. DEG
TOTAL FORCE	68.382		62.578	-8.5 %
NORMAL FORCE	67.013		60.837	-9.2 %
FRICTION FACTOR	.203		.241	
FRICTION FORCE	13.615		14.661	7.7 %
FRICTION DIRECTION	78.		146.	67. DEG
FROM THE HORIZONTAL				

SEGMENT NUMBER 2 FILE NAME POS_14
 AUG 26 CALIBRATION POSITION POS 14

TRANSDUCER	READING (N)
R-21	9.59
R-22	2.28
H-21	10.46
H-22	8.38
H-23	1.84
V-21	10.45
V-22	9.62
V-23	5.32
V-24	9.31
V-25	1.12
T'V	16.34
T'L	-3.31
NOR	46.95

	APPLIED	MEASURED	% ERROR
FORCES IN X	15.12	11.87	-21.
Y	15.95	20.68	30.
Z	44.72	35.83	-20.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -3.18 X PLANE
 C2= 8.29 Y PLANE
 C3= -3.79 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.873	.004 m
Z=	.133	.127	-.006 m
WATERPLANE ANGLE	35.	34.	-0. DEG
FLARE ANGLE	51.	50.	-0. DEG
TOTAL FORCE	49.827	43.035	-13.6 %
NORMAL FORCE	46.955	42.075	-10.4 %
FRICTION FACTOR	.355	.215	
FRICTION FORCE	16.675	9.040	-45.8 %
FRICTION DIRECTION FROM THE HORIZONTAL	79.	102.	23. DEG

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SEGMENT NUMBER 2 FILE NAME WPOS_14
 SEPT 5 CALIBRATION POSITION WPOS_14

TRANSDUCER	READING (N)
R-21	13.47
R-22	1.49
H-21	13.53
H-22	15.98
H-23	2.98
V-21	9.01
V-22	19.04
V-23	6.27
V-24	4.45
V-25	-1.31
T'V	3.45
T'L	-3.08
NOR	62.83

	APPLIED	MEASURED	% ERROR
FORCES IN X	26.54	14.95	-44.
Y	32.79	32.48	-1.
Z	46.80	37.47	-20.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-3.81	X PLANE
C2=	10.08	Y PLANE
C3=	-5.29	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.869	1.906	.037 m
Z=	.133	.091	-.042 m
WATERPLANE ANGLE	35.	32.	-2. DEG
FLARE ANGLE	51.	48.	-2. DEG
TOTAL FORCE	63.005	51.794	-17.8 %
NORMAL FORCE	62.835	51.493	-18.1 %
FRICTION FACTOR	.074	.108	
FRICTION FORCE	4.624	5.583	20.7 %
FRICTION DIRECTION	48.	149.	100. DEG
FROM THE HORIZONTAL			

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SEGMENT NUMBER 2 FILE NAME POS_15
 AUG 26 CALIBRATION POSITION POS 15

TRANSDUCER	READING (N)
R-21	13.61
R-22	3.97
H-21	21.82
H-22	-1.46
H-23	1.09
V-21	26.35
V-22	26.69
V-23	-8.61
V-24	12.74
V-25	.62
T'V	31.32
T'L	-2.62
NOR	68.03

	APPLIED	MEASURED	% ERROR
FORCES IN X	15.74	17.58	12.
Y	15.94	21.46	35.
Z	71.51	57.80	-19.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1= -2.37 X PLANE
 C2= 18.95 Y PLANE
 C3= -7.09 Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.979	1.967	-.012 m
Z=	.133	.130	-.003 m
WATERPLANE ANGLE	38.	37.	-1. DEG
FLARE ANGLE	55.	54.	-1. DEG
TOTAL FORCE	74.933	64.111	-14.4 %
NORMAL FORCE	68.025	61.372	-9.8 %
FRICTION FACTOR	.462	.302	
FRICTION FORCE	31.425	18.541	-41.0 %
FRICTION DIRECTION	85.	87.	2. DEG
FROM THE HORIZONTAL			

SEGMENT NUMBER 2 FILE NAME WPOS_15
 SEPT 5 CALIBRATION POSITION WPOS_15

TRANSDUCER	READING (N)
R-21	10.40
R-22	1.49
H-21	16.32
H-22	-.78
H-23	.99
V-21	21.91
V-22	24.37
V-23	-6.86
V-24	8.21
V-25	.44
T'V	28.40
T'L	-4.56
NOR	64.21

		APPLIED	MEASURED	% ERROR
FORCES IN	X	17.03	11.89	-30.
	Y	14.44	16.54	15.
	Z	66.72	48.07	-28.

MOMENTS ABOUT SHIP ORIGIN AT 24.75 FT WATERLINE

C1=	-2.45	X PLANE
C2=	16.35	Y PLANE
C3=	-5.44	Z PLANE

	APPLIED	MEASURED	ERROR
LOCATION :X=	1.979	1.971	-.008 m
	Z= .133	.125	-.008 m
WATERPLANE ANGLE	38.	37.	-1. DEG
FLARE ANGLE	55.	54.	-1. DEG
TOTAL FORCE	70.358	52.208	-25.8 %
NORMAL FORCE	64.208	49.226	-23.3 %
FRICTION FACTOR	.448	.353	
FRICTION FORCE	28.768	17.392	-39.5 %
FRICTION DIRECTION	81.	92.	11. DEG
FROM THE HORIZONTAL			

APPENDIX G.3

PRELIMINARY SEGMENT 2 CORRECTED RESULTS



G.3 Segment Correction Factors

Based on the entire set of preliminary calibrations performed on the segment, correction factors were applied to the outputs of Segment 2's transducers in order that they better predict the applied load.

As ice loads are expected to occur primarily above the 23' W.L. correction factors derived for this area of the segment were used. The correction factors essentially removed the mean error found during external calibrations.

The segment correction factors implemented were:

- 0.97 to the three horizontal transducers H_{21} , H_{22} , and H_{23} .
- 1.21 to the 5 vertical transducers V_{21} , V_{22} , V_{23} , V_{24} and V_{25} . This is in addition to the correction factors of 0.86 and 0.78 which were applied to V_{22} and V_{23} respectively as a result of the tensioning calibrations.

In the longitudinal direction it was theorized that since this force is consistently under predicted by the segment perhaps friction is occurring at the other transducers. R_{21} , the stiffest transducer in the longitudinal direction, has a stiffness of 6.8 MN/m. It is possible that this is low enough to allow enough movement of the segment, 3-6 microns, so that the ball bearings of the other load cells move enough inside their cups that they contact the wall of their cups. If the bearing contacts the wall friction between the wall and the bearing will stop the bearing from rolling and instead it will slide on its bearing pad. Sliding friction between steel has a friction coefficient of 0.1 to 0.15. Multiplying the axial load of each transducer by a friction coefficient will give the amount of longitudinal load which is being carried by friction. Therefore the longitudinal load has been corrected as follows:

$$F_{xm} = \sum_{i=1} R_{2i} + .11 \sum_{i=1} H_{2i} + .11 \sum_{i=1} V_{2i}$$

where .11 has been chosen as the friction coefficient. Also the sum of the moments in the x, y and z planes have been changed to include the friction forces.

Empirical correction factors were also applied to the x and z positions, since they seem to have a consistent offset. The corrections are

$$X_m = X - 18$$

$$Z_m = Z + 10$$

where the units are mm.

CORRECTED CALIBRATION RESULTS:

The corrected results are summarized in Table G.3. With the empirical constants in place for the longitudinal, horizontal and vertical transducers and corrections applied to the algorithm, the errors in the normal applied load have been reduced to reasonable levels of $\pm 7\%$ of the applied load. The location of the load can be found to within $\pm 16\text{mm}$ vertically and $\pm 20\text{mm}$ longitudinally.

If only the in-air calibrations are considered the load can be located to within $\pm 9\text{mm}$ vertically. This is logical since during the in-air calibrations the position of the load can be visually checked. Therefore this can be considered as a more valid bound on the error. Table 5.5 is a summary of errors in the prediction of the normal force, friction force, x position of the load and z position of the load, using the corrected test results.

The friction force has a large error due to its low magnitude. It can be found to within $\pm 32\%$ but a more realistic analysis is to examine the error in Newtons which has a standard deviation of 3.8N. The friction force is then accurate to within $\pm 4\text{N}$.

Table G.3 Summary of Preliminary Corrected Segment 2 Calibrations

Calibration Position	Air or Water (A/W)	Total Applied Force Newtons	% error in Normal Force	Error in Normal Force Newtons	% error in Friction Force	Error in Friction Newtons	Error in x position mm	Error in z position mm
1	A	81.4	0	-0.2	8	1.7	-1	5
1*	W	55.0	-4	-2.0	-61	-11.9	19	11
2	A	76.8	0	0.0	3	0.5	-1	0
2	W	79.9	3	2.5	18	2.0	-10	9
3	A	79.9	-1	-0.9	-9	-1.7	-1	0
3*	W	76.7	5	3.8	26	4.4	-33	13
4	A	84.7	4	3.4	-9	-2.2	6	53
4*	W	93.6	3	3.0	-46	-17.0	21	53
5	A	68.1	-8	-5.0	7	1.4	3	-5
5	W	79.5	-1	-0.4	32	3.1	17	18
6*	A	96.3	3	2.8	-21	-8.9	-7	5
6*	W	84.6	-1	-0.7	12	3.1	-1	15
7	A	96.1	-5	-4.5	-7	-1.2	-1	-13
7	W	78.0	5	4.1	-3	-0.6	-36	12
8	A	80.4	-5	-4.4	15	1.3	0	15
8	W	84.5	4	4.4	33	4.1	-34	11
9	A	67.4	1	0.8	-22	-4.7	10	-3
9	W	79.4	-4	-3.1	-50	-8.6	31	8
10	A	82.0	-3	-2.4	-32	-4.2	-11	-1
10	W	84.5	3	2.4	-44	-8.2	-2	9
11	A	32.4	2	0.6	52	0.8	-18	2
11	W	43.3	1	0.5	-42	-4.6	7	-5
12*	A	86.2	8	6.3	-28	-11.8	27	11
12	W	68.4	7	4.5	-57	-7.7	52	16
13	A	59.1	6	2.4	-58	-6.2	17	12
13	W	68.4	7	4.6	-19	-2.5	20	15
14*	A	49.8	6	3.0	-29	-4.7	-1	4
14	W	63.0	-5	-3.2	34	1.6	28	-31
15*	A	74.9	9	6.1	-23	-7.2	-17	6
15*	W	70.4	-7	-4.5	-24	-7.0	-14	0
Maximum		96.3	7	4.5	52	4.1	52	16
Minimum		32.4	-8	-5.0	-58	-8.6	-36	-31
Mean		73.2	0	-2.3	-1	5.0	3	0
Stand. Dev		14.9	4	10.0	32	3.8	20	16

* indicates that the calibration result was not used in the statistical analysis

APPENDIX H

MODELLING AND ANALYSIS OF UNCERTAINTY IN THE SEGMENT MEASUREMENTS

MODELLING AND ANALYSIS OF UNCERTAINTY IN THE SEGMENT MEASUREMENTS

In agreement with the principles of measurement theory, the estimated mean value from a set of measurements is usually used to represent the true value of the measured quantity. The error associated to the estimated value consists of systematic and random components. The systematic component may be the result of a certain well-identified factor whose effects can be corrected through a constant bias factor, whereas the random component may be represented as a range of possible values. The systematic error, therefore, is a bias in the measured value, whereas the random error represents the degree of dispersiveness of the range of possible errors.

In general, therefore, the systematic error in the measured value may be corrected by applying a constant bias factor; however, the random error requires a statistical treatment and may be represented by the standard deviation or coefficient of variation of the estimated mean value. In order to study these errors in the context of the measured forces used during the calibration described in section 5, the following approach is used.

Suppose that the true force is F , whose actual realization is unknown. Prediction or estimation of F , therefore is necessary; for this purpose a measured force denoted by $\hat{F}$ may be used. Since $\hat{F}$ is a measurement of the real world, inaccuracies in the measurement may be expected; the measured values therefore contain errors and a correction γ may be applied. Consequently the true force may be represented by:

$$F = \frac{\hat{F}}{\gamma} \quad (\text{H.1})$$

with mean value

$$\bar{F} = \frac{\bar{\hat{F}}}{\bar{\gamma}} \quad (\text{H.2})$$

and standard deviation

$$\sigma_F = \frac{\bar{F} \sigma_{\gamma}}{\bar{\gamma}} \quad (\text{H.3})$$

where the mean value of the correction $\bar{\gamma}$ represents the mean correction for systematic error in the mean value of F , whereas the standard deviation σ_{γ} represents the random error in the predicted mean value of F .

In each segment and for each of the forces of interest, the statistical parameters of the correction γ were estimated using the ratios of measured/calibrating forces reported in tables 5.1 5.6 and 5.10 and shown graphically as a function of the measured force in Figures H.1 - H.15. In the estimation of the parameters all the reported data were given equal weight since apparently no sound reasons exist to consider the typical values as outliers. From the study of the plots it was concluded that most of the data are spread around a constant mean value with a constant variance, in other words no trends are identified. Exceptions were some of the data for segment 3.

The data corresponding to F_x in segment 3 suggests the existence of a constant mean value of the correction and a monotonically decreasing variance as the measured force increases. The data for F_z and F_f shows a monotonically increasing trend on the mean values of γ as the measured forces increase. However, the variance of the data seem to be constant in both cases.

Results of the statistical calculations are shown in Table H.1. The greatest random errors are associated to the measurement of F_x while the smallest random error correspond to the measurements of F_y . The mean value of the correction factor and the range of ± 1 standard deviation confidence limits (68% confidence interval) are plotted in Figures H.1 - H.15.

Using the results in Table H.1 and equations H.2 and H.3 the true (mean) applied force and its confidence limits can be obtained. An interval of two standard deviations (± 1 standard deviation) about the measured force means that the confidence limits are 68%. It is 68% certain that the true force lies inside this interval. As the range around the measured force increases the confidence limits increase as well. A 95.4% confidence limit exists for a range of 4 standard deviations (± 2 standard deviations). These confidence limits assume that the error is Gaussian. Plots of the error have confirmed this assumption. Figure H.16 shows these values for F_z in segment 3 with a 68% confidence limit, as an example of what the error bounds look like when plotted.

It is remarked that in general, the parameters of the correction factor shown in Table H.1 are only valid for the range of values they were derived from. Extrapolating out of that range should be done with precaution, specially for those variables in which trends were identified.

Finally, it is recommended that further calibration studies be conducted to observe the variability on repetitive measurements of the same applied load intensity and to widen up the range of measured values.

TABLE H.1
MEAN VALUE AND STANDARD DEVIATION OF THE CORRECTION FACTOR

FORCE	SEGMENT 1		SEGMENT 2		SEGMENT 3	
	$\bar{\gamma}$	σ_{γ}	$\bar{\gamma}$	σ_{γ}	γ	σ_{γ}
F_x	1.279	0.432	0.744	0.184	1.170	.6038 (-2X+2.6)*
F_y	1.036	0.074	1.094	0.077	0.950	0.048
F_z	1.132	0.117	1.090	0.142	.0202X+ .5486*	0.108
F_n	1.106	0.098	1.001	0.132	.943	0.043
F_f	1.250	0.396	1.217	0.4734	.048X + .0422*	0.135

* where X is the measured force of interest.

FIGURE H.1
Measured Fx vs Ratio Fx

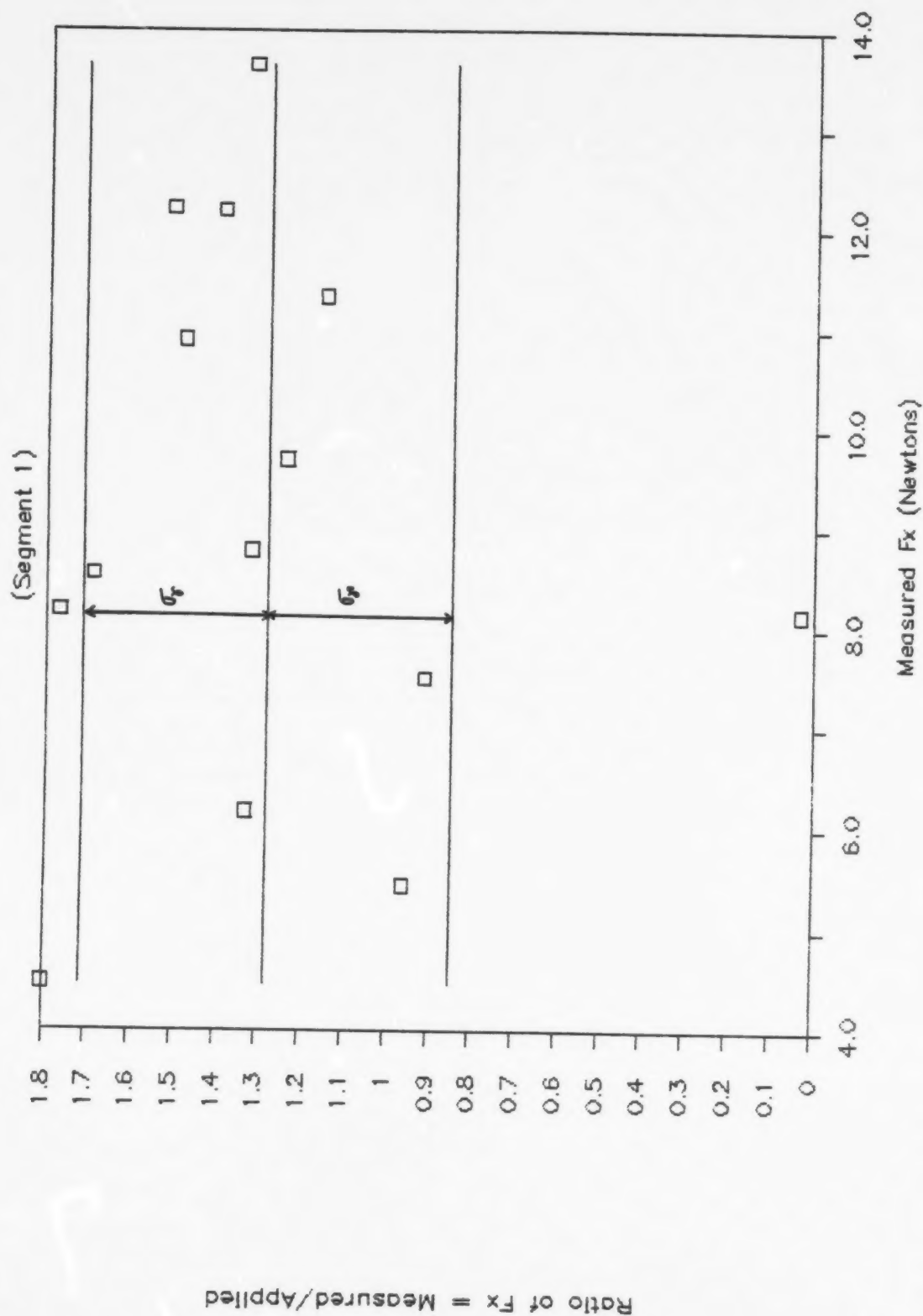


FIGURE H.2
Measured F_y vs Ratio F_y
(Segment 1)

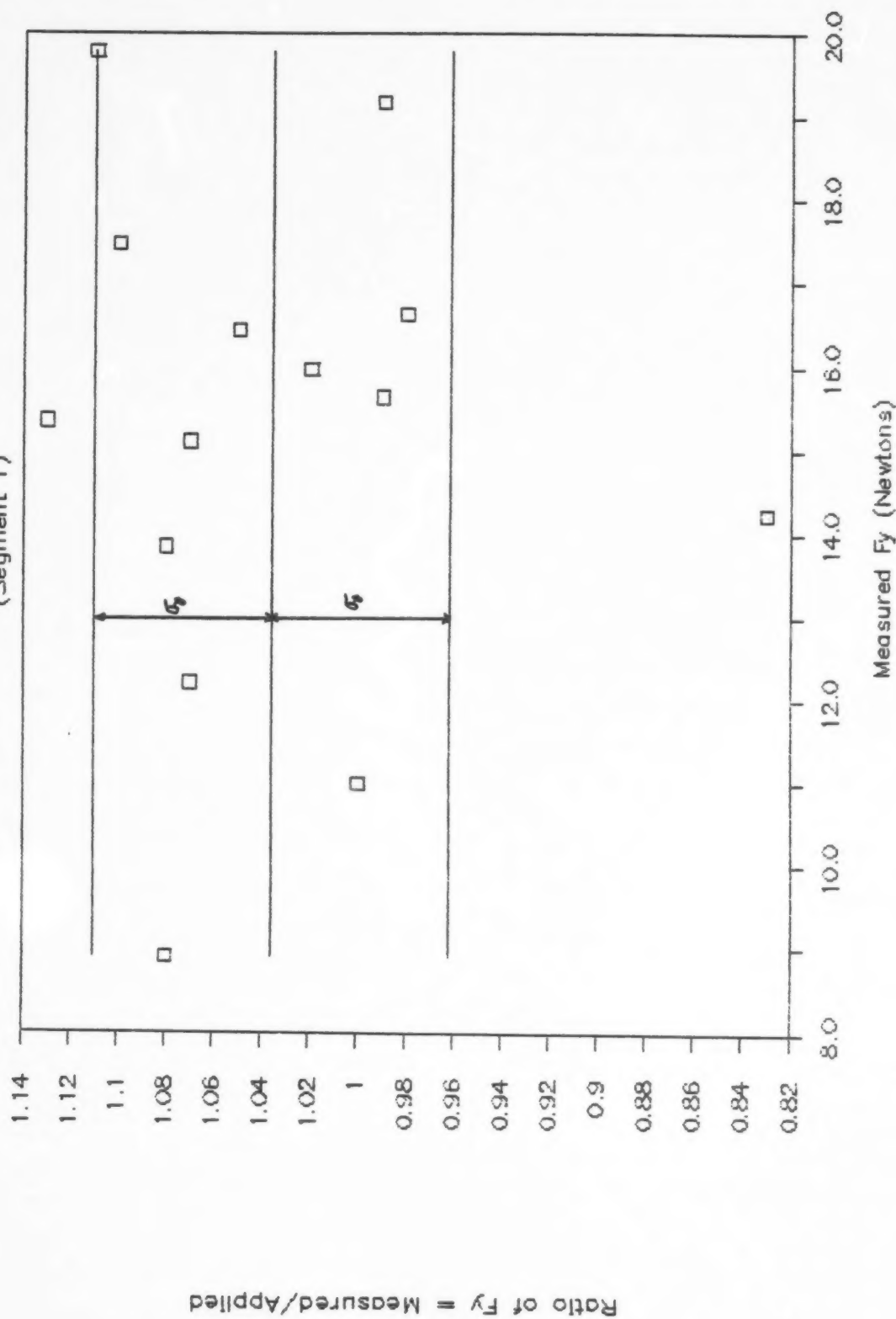


FIGURE H.3

Measured Fz vs Ratio Fz

(Segment 1)

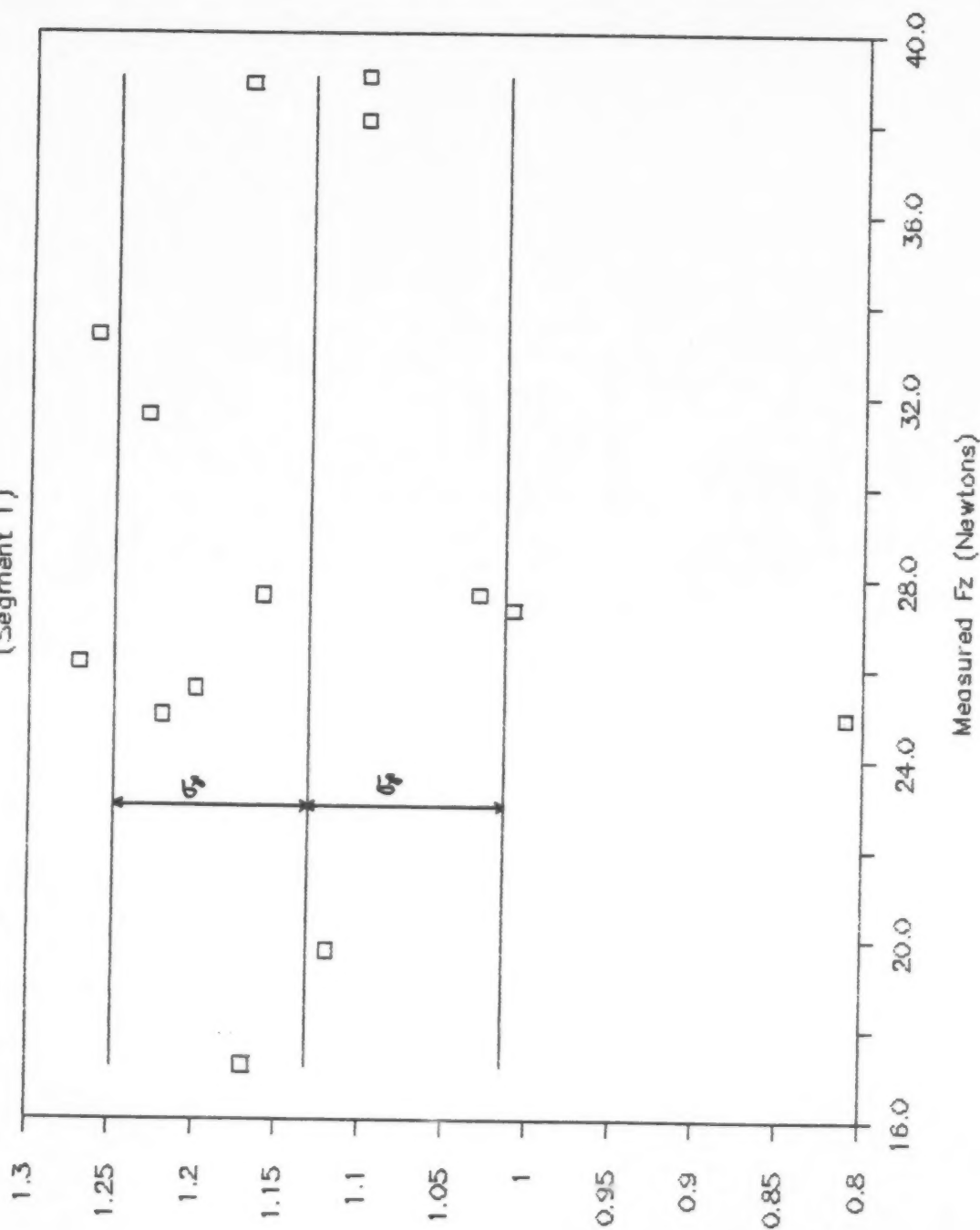


FIGURE H.4
Measured F_n vs Ratio F_n
(Segment 1)

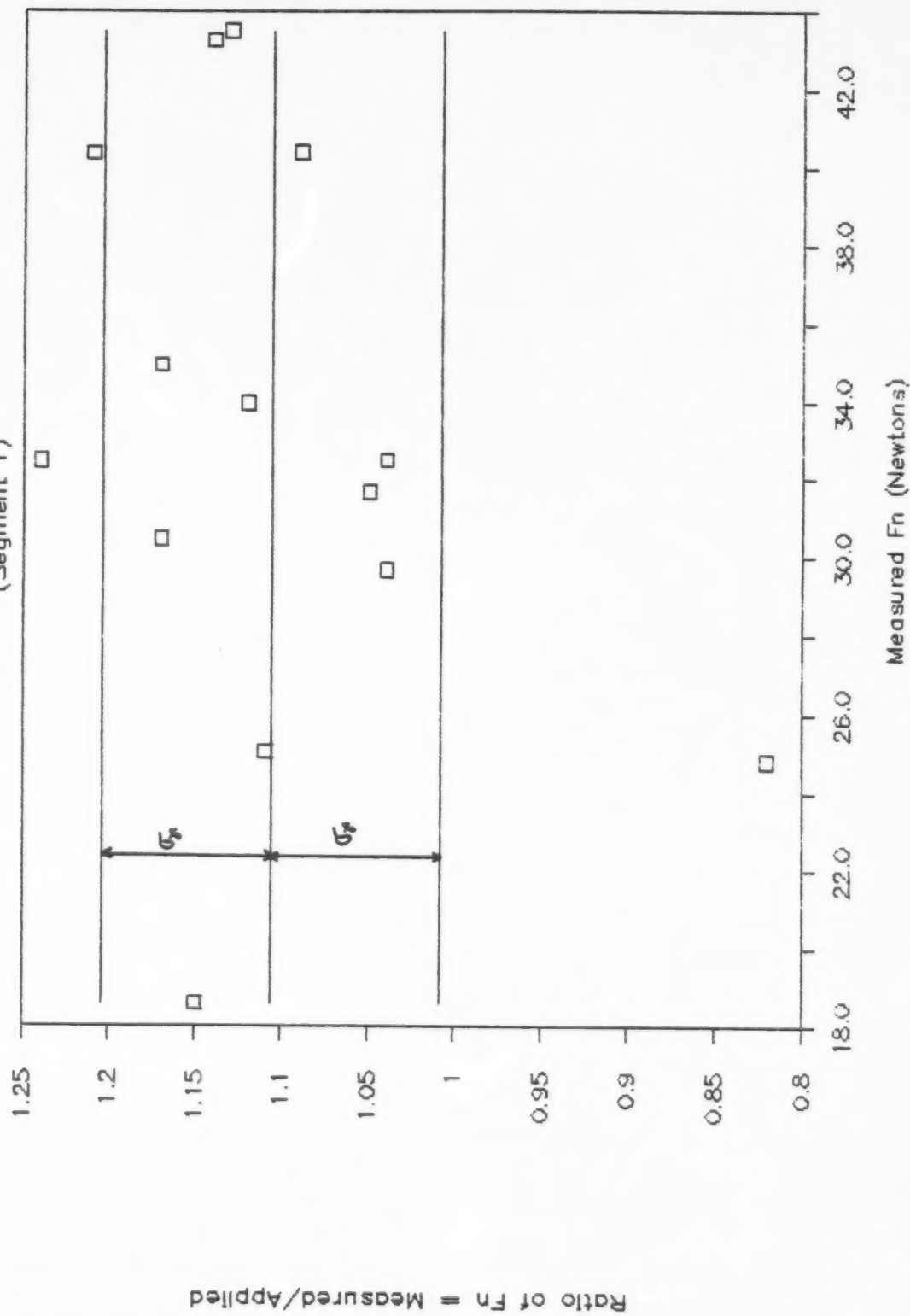


FIGURE H.5

Measured F_f vs Ratio F_f

(Segment 1)

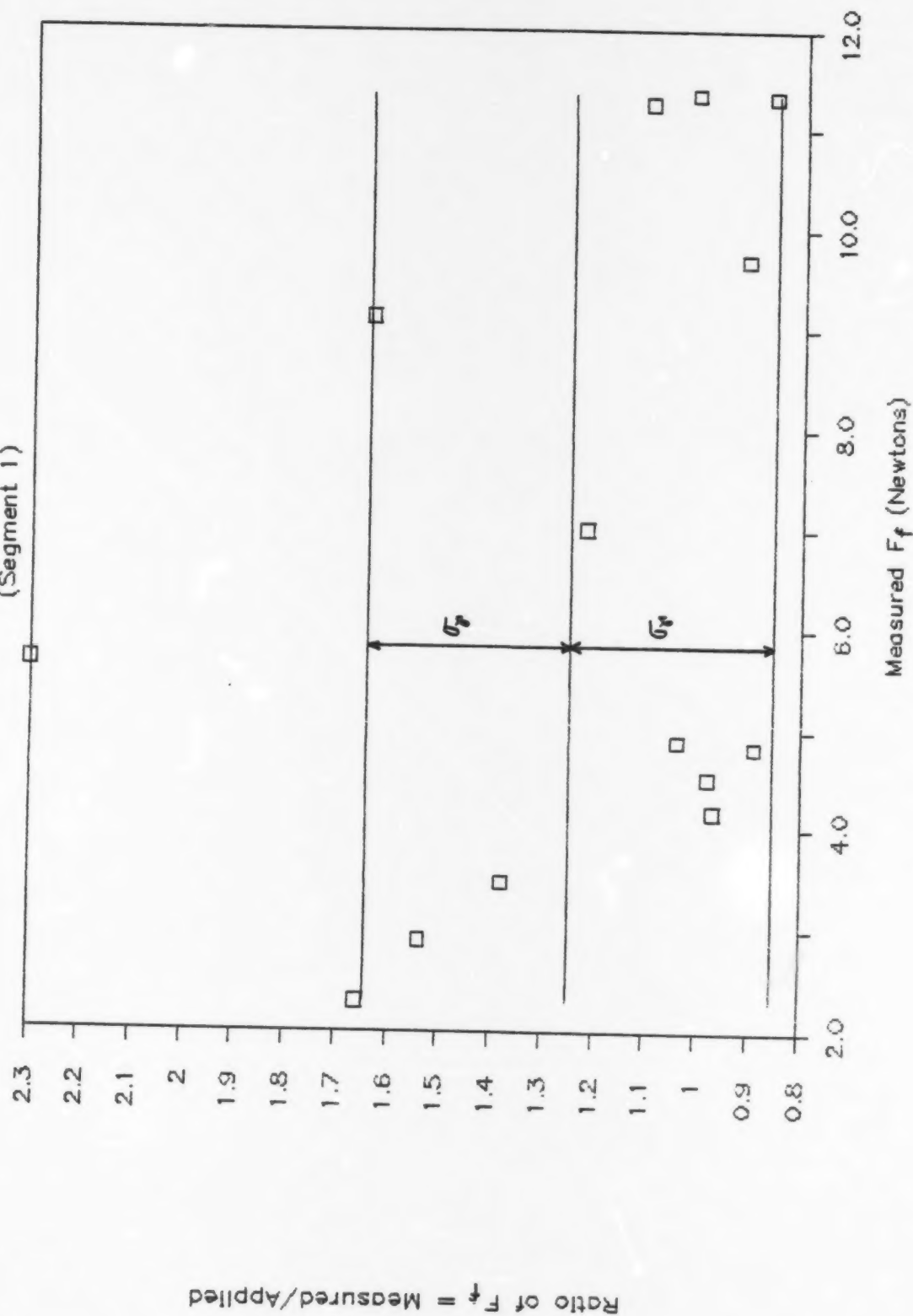


FIGURE H.6
Measured F_x vs Ratio of F_x
(Segment 2)

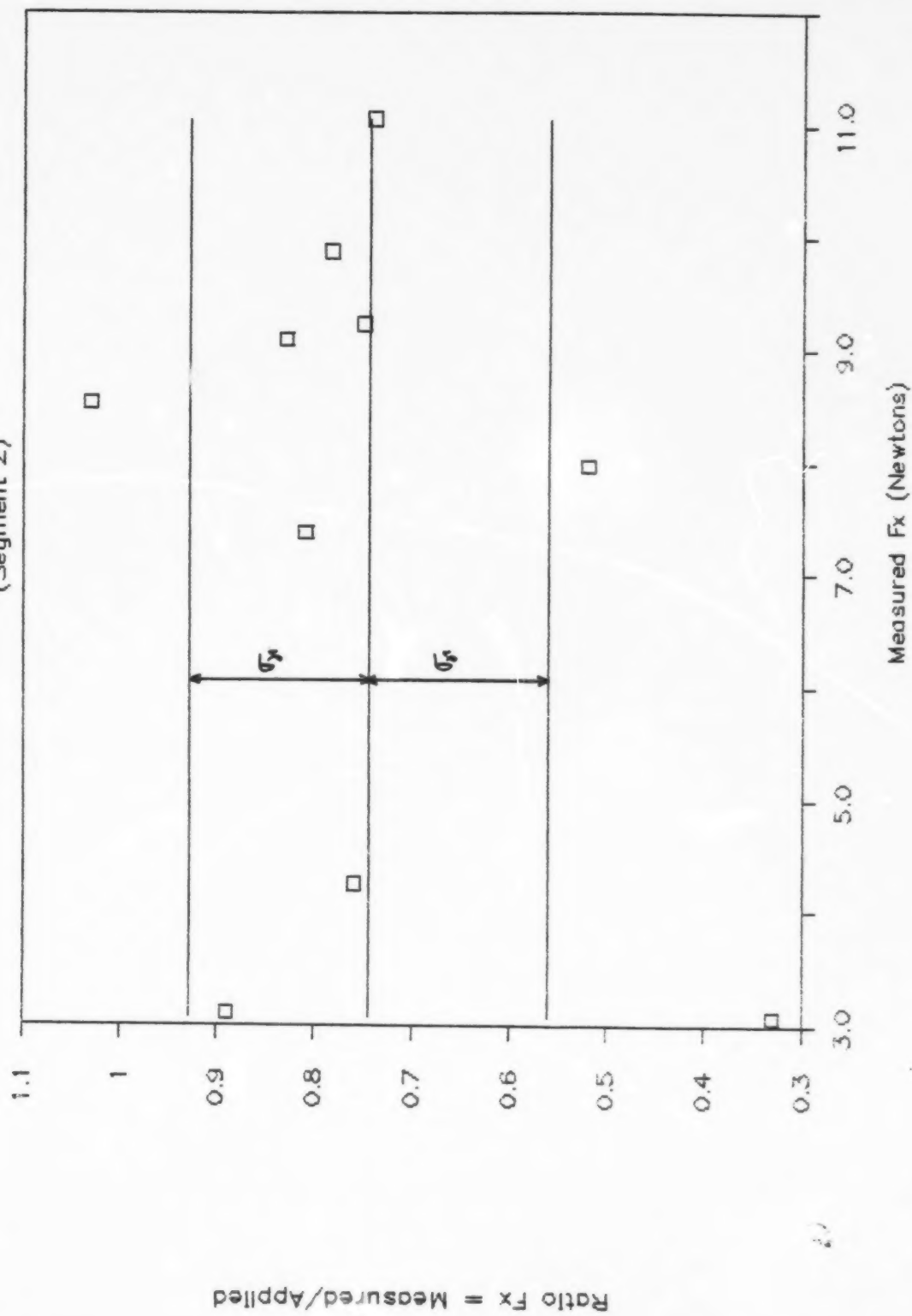


FIGURE H.7

Measured F_y vs Ratio of F_y

(Segment 2)

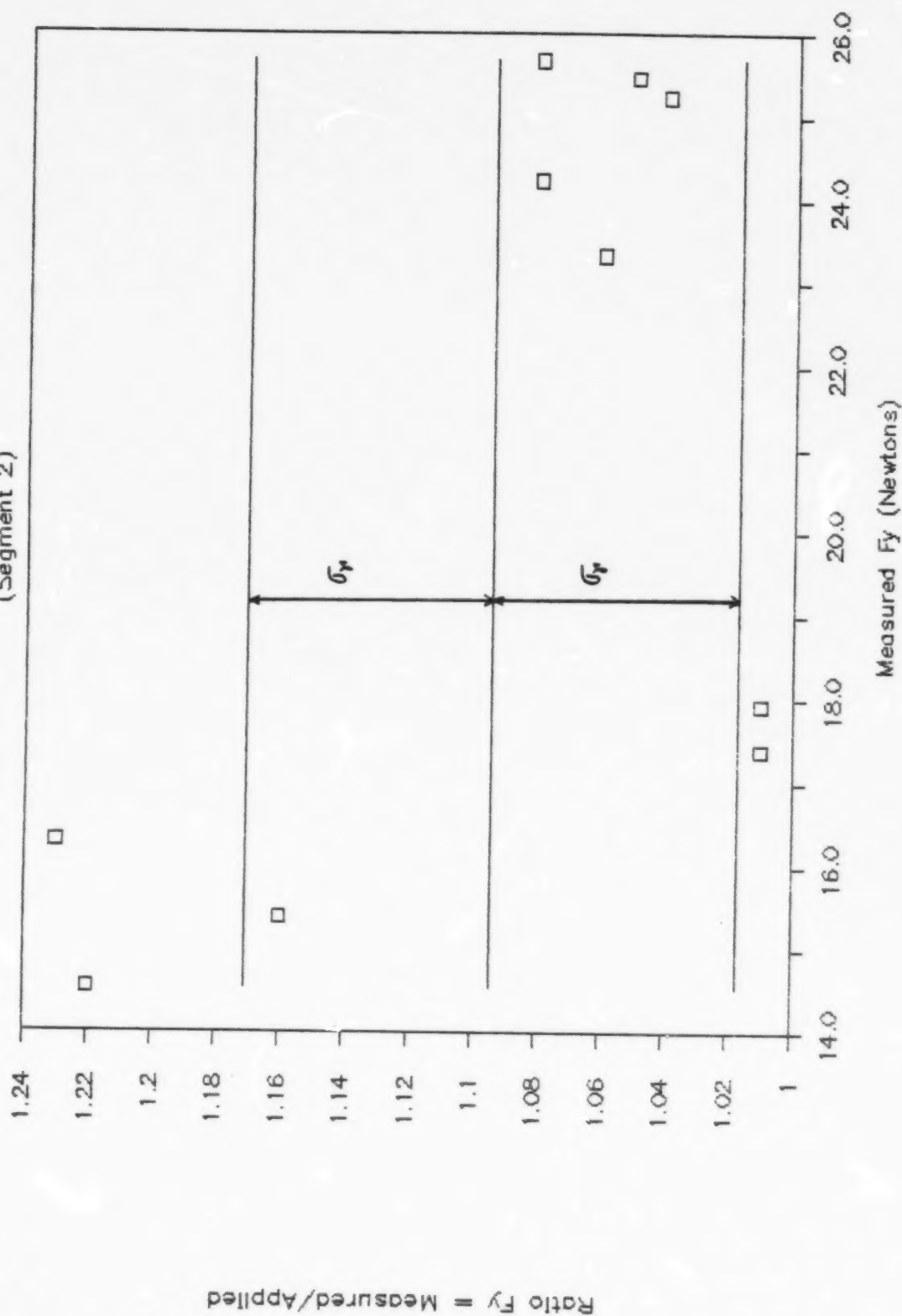


FIGURE H.8
Measured Fz vs Ratio of Fz
(Segment 2)

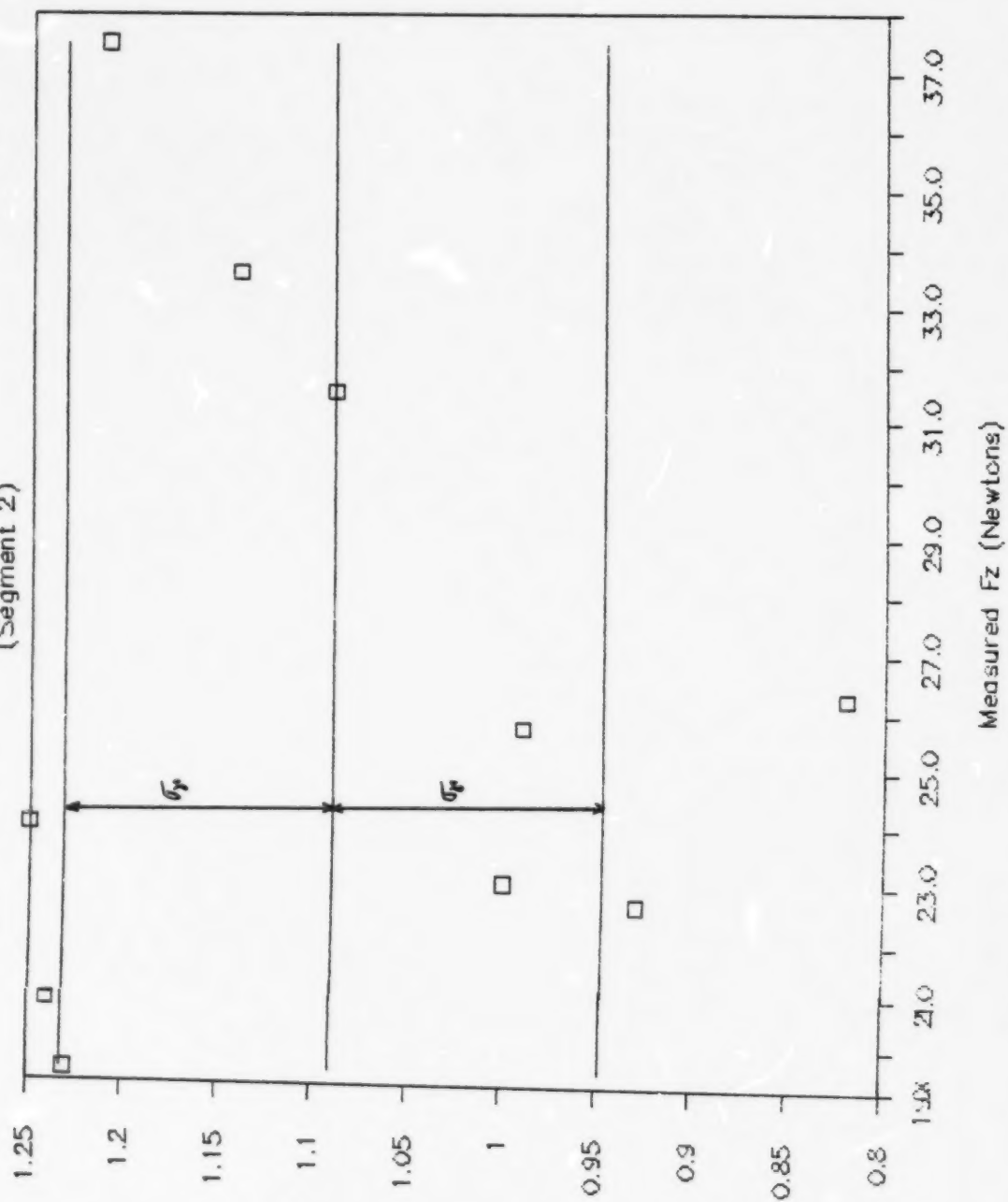


FIGURE H.9

Measured F_n vs Ratio of F_n

(Segment 2)

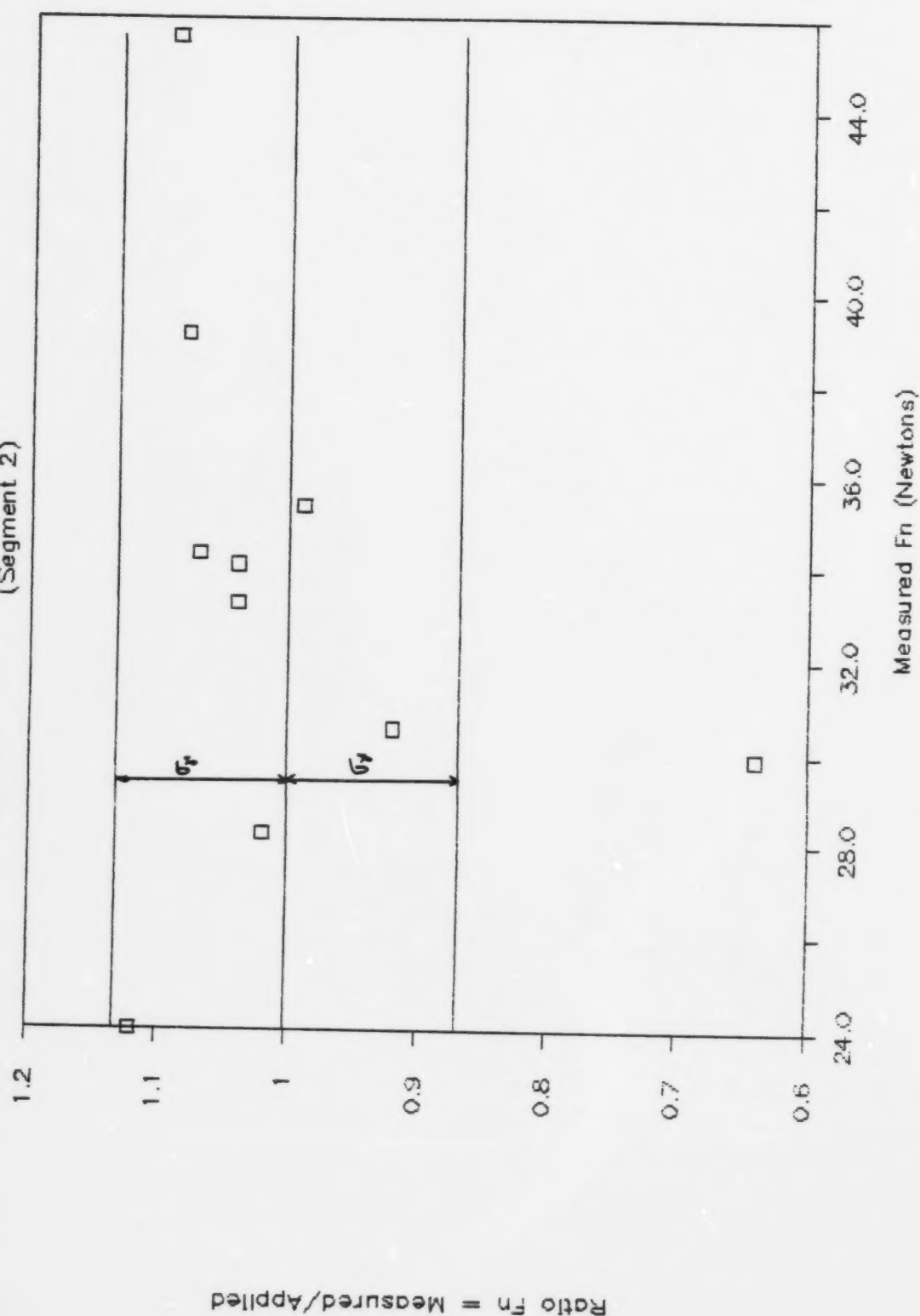


FIGURE H.10
Measured F_f vs Ratio of F_f
(Segment 2)

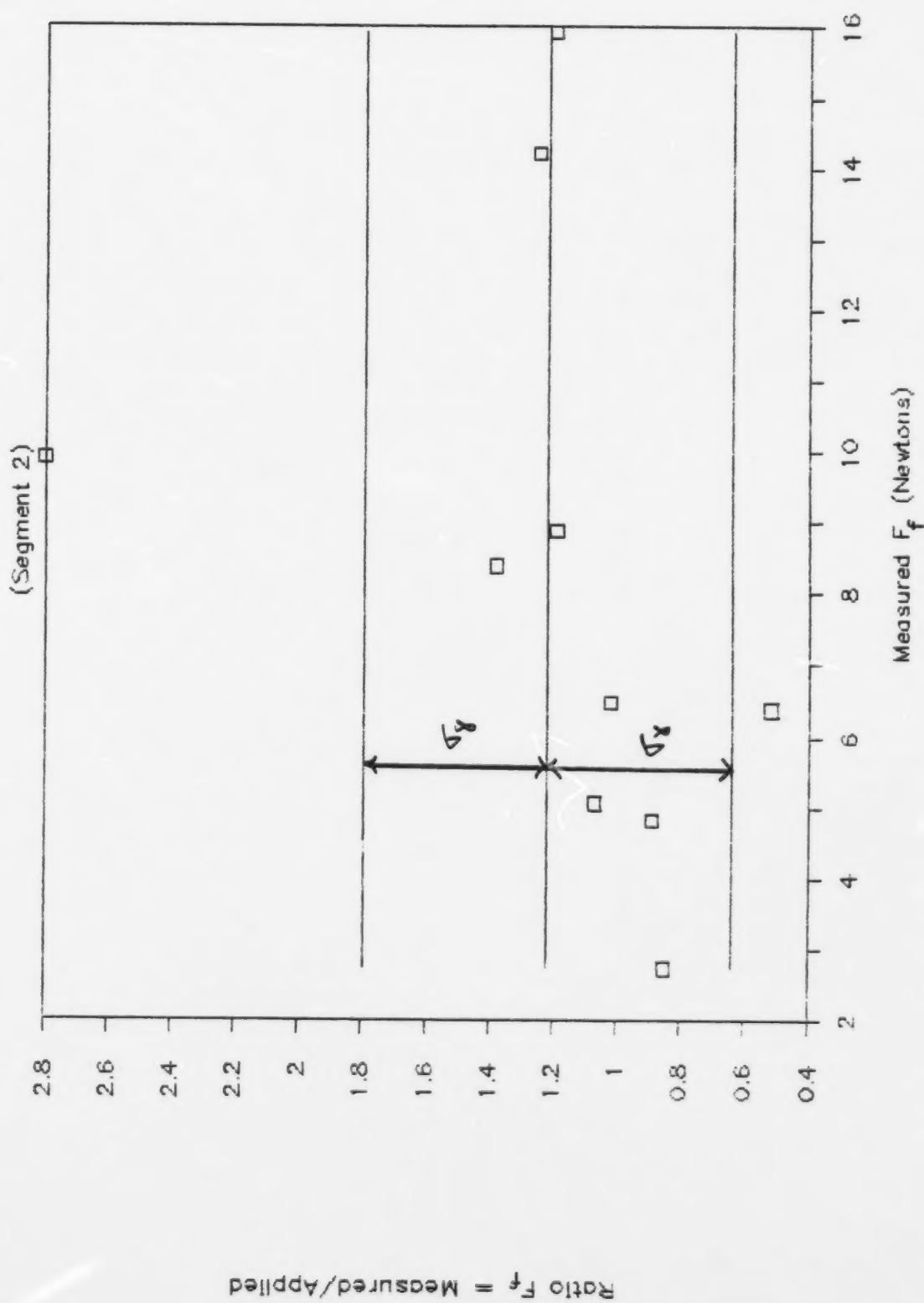


FIGURE H.11
Measured F_x vs Ratio F_x
(Segment 3)

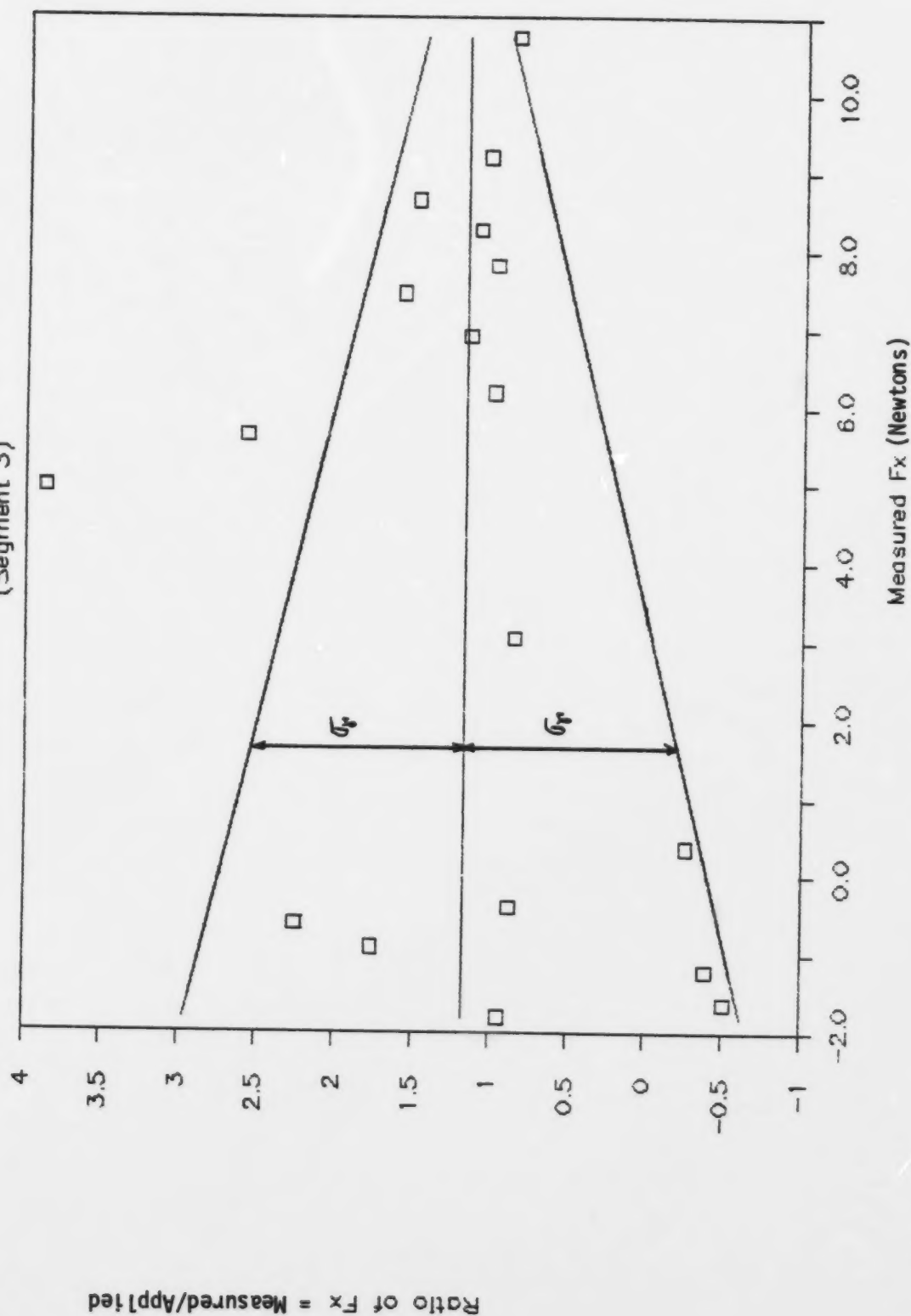


FIGURE H.12
Measured F_y vs Ratio F_y
(Segment 3)

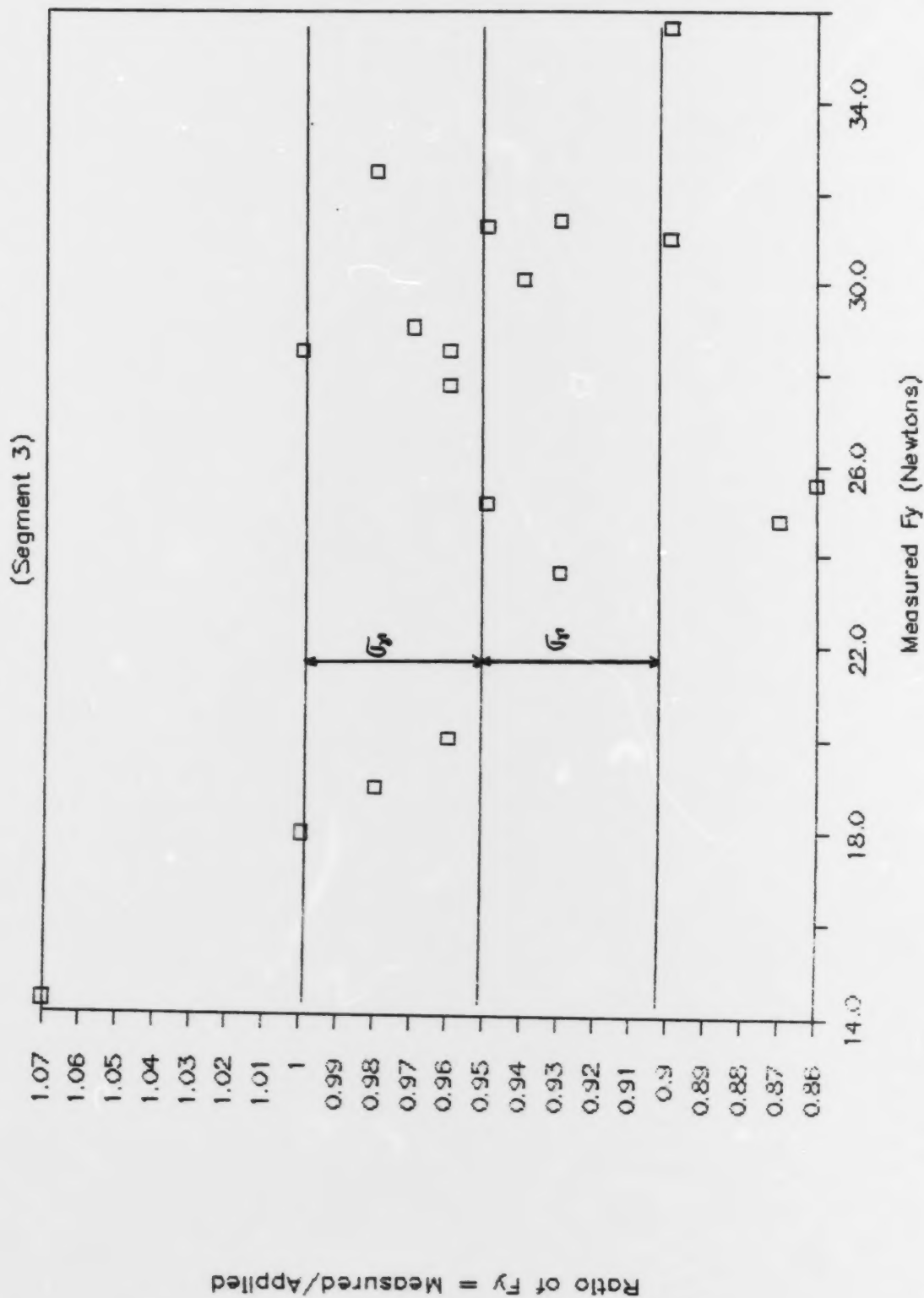


FIGURE H.13

Measured F_z vs Ratio F_z

(Segment 3)

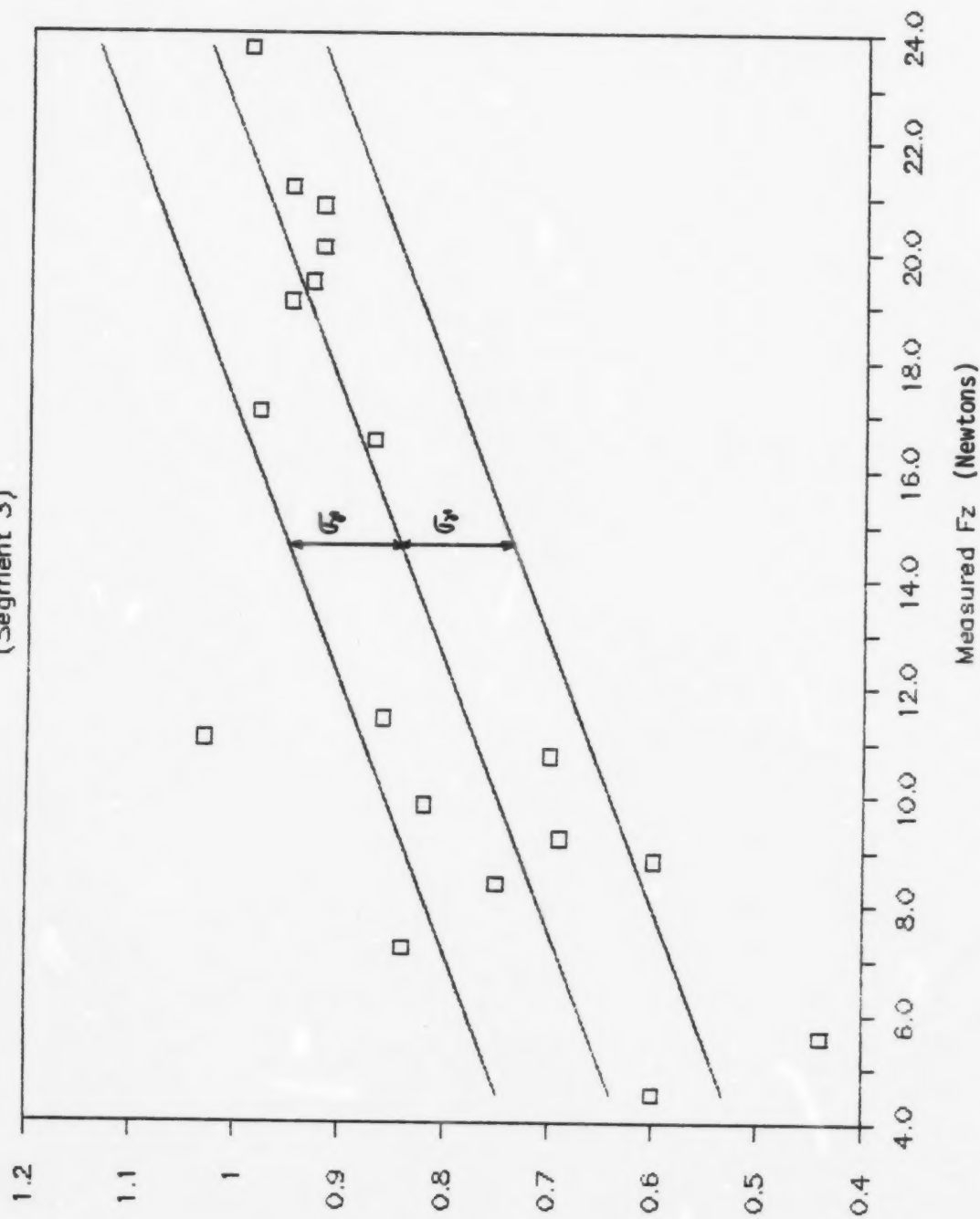


FIGURE H.14

Measured F_n vs Ratio F_n

(Segment 3)

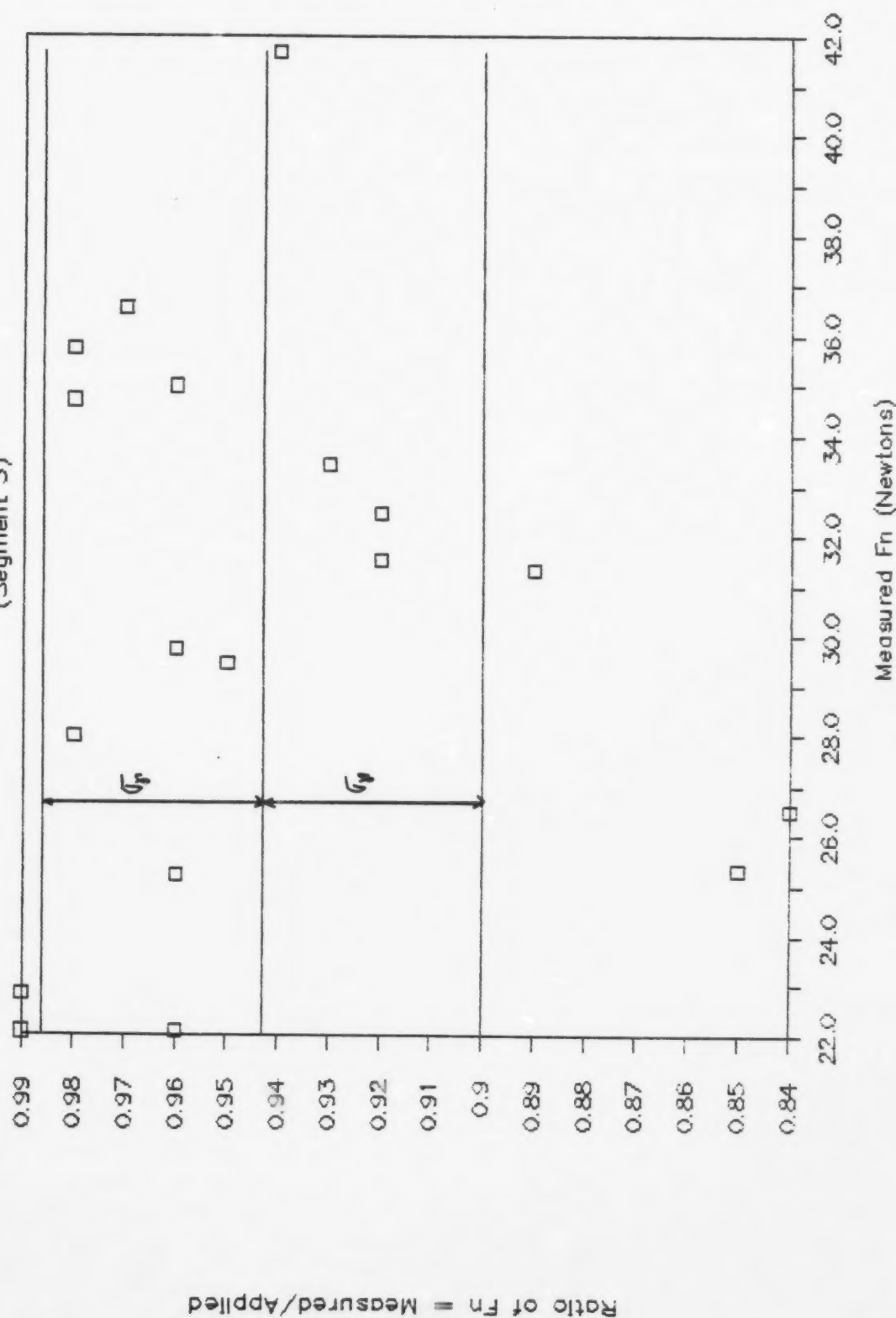


FIGURE H.15
Measured F_f vs Ratio F_f
(Segment 3)

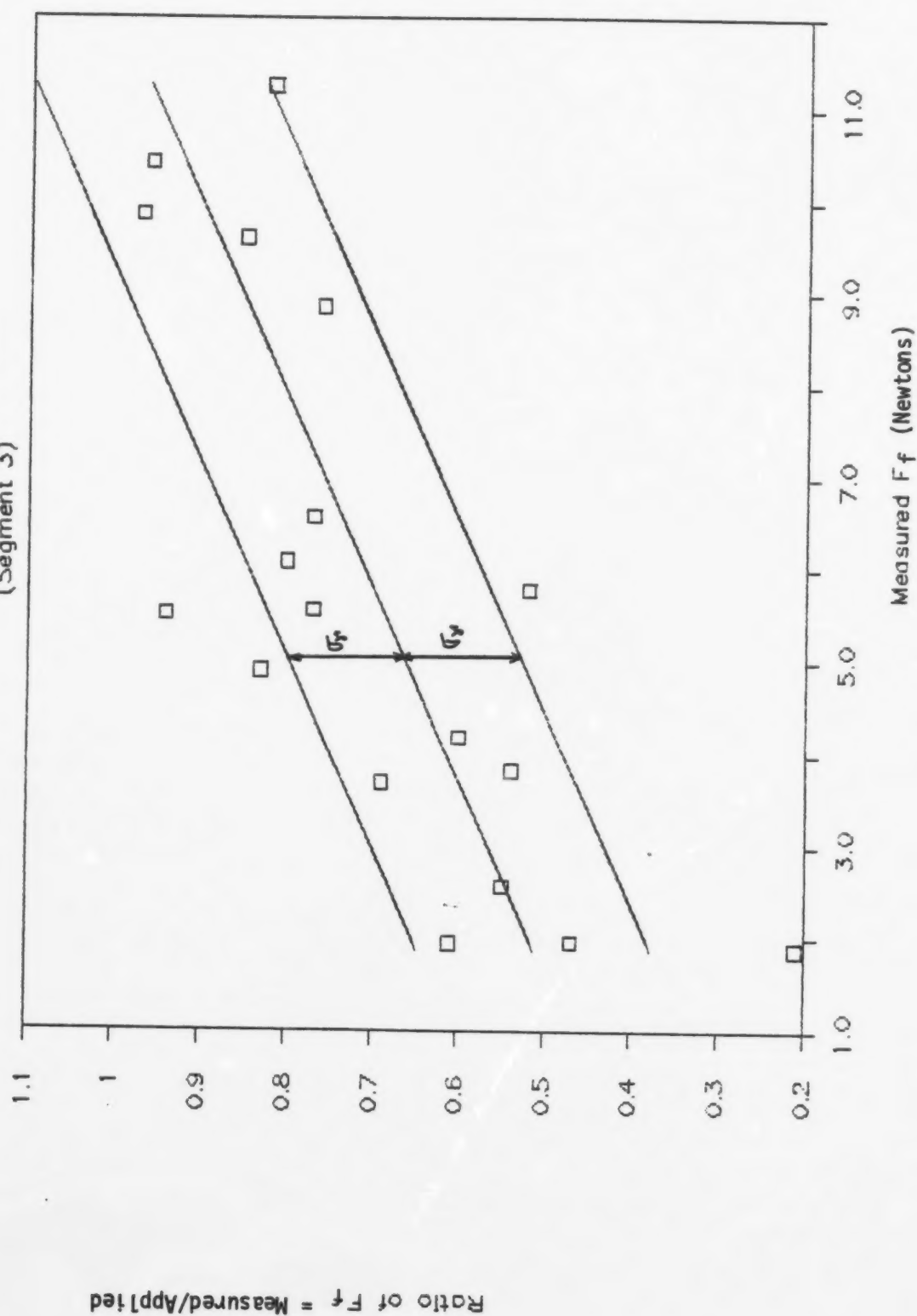
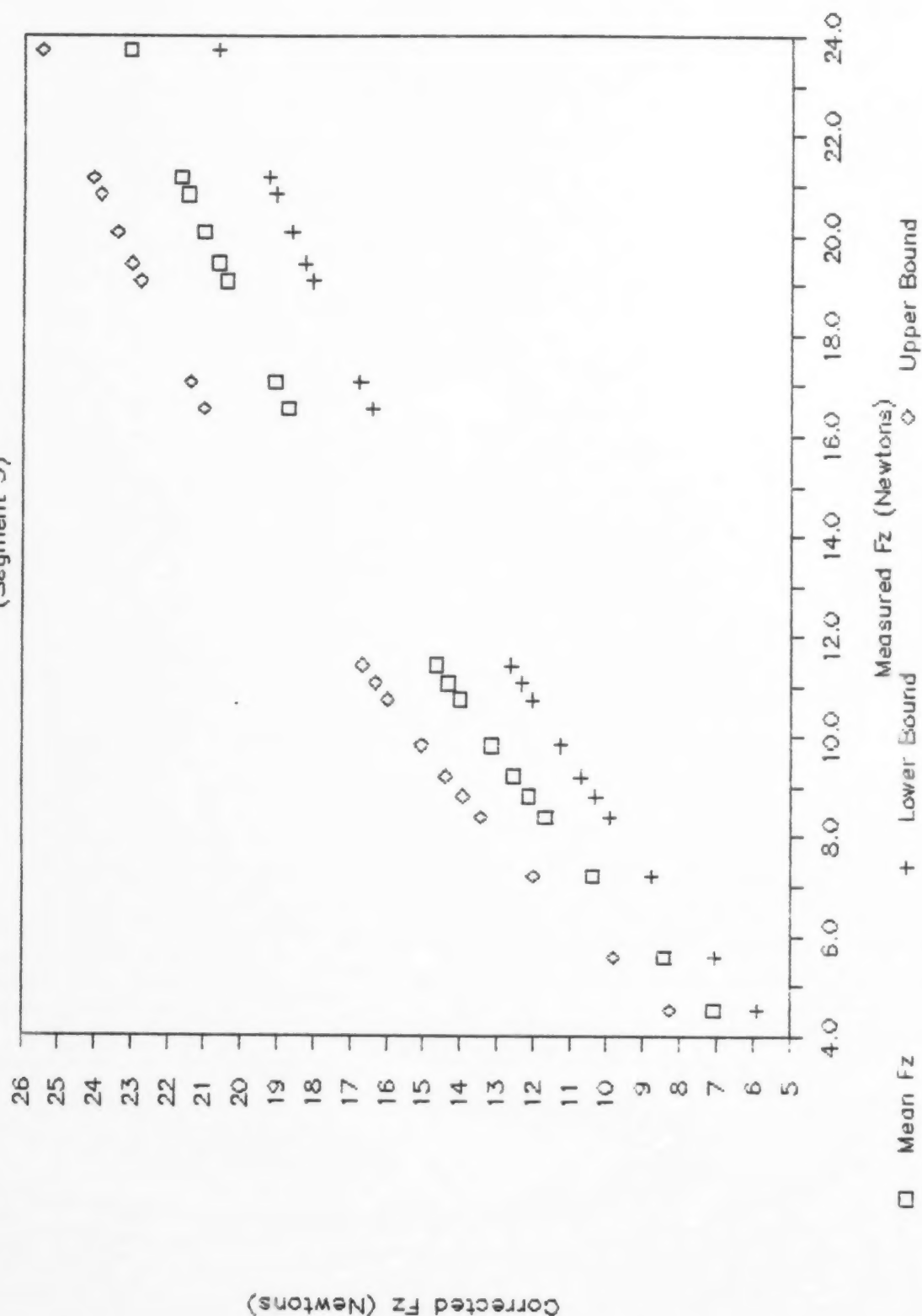


FIGURE H.16

Measured Fz vs Corrected Fz

(Segment 3)



APPENDIX I.1

HEAVE, PITCH AND ROLL CALIBRATION TEST DATA SHEETS

This appendix contains the results of the heave, pitch, and roll calibrations. The measurement of each transducer as well as the heave, pitch, and roll measurements are given with the zero reading subtracted. Heave is given in the units of millimetres and pitch and roll are given in degrees. One to two measurements were made in each test using the procedure described in Section 6, Volume I.

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PROJECT 1566C

NOV 21 SEGMENT NUMBER 4 FILE NAME HEAV3
CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	0.00	0.00
H-11	0.00	0.00
H-12	0.00	0.00
V-11	.39	.78
V-12	.40	.60
V-13	.18	.37
RV-1	.12	.12
HV-1	0.00	0.00
R-21	.33	.41
R-22	0.00	0.00
H-21	0.00	0.00
H-22	.28	0.00
H-23	0.00	-.20
V-21	.82	1.83
V-22	.74	1.20
V-23	1.40	2.34
V-25	-.25	.50
R-31	-.41	-.87
R-32	-.19	-.19
H-31	.41	.21
H-32	-.18	-.53
H-33	.39	.29
V-31	.81	1.73
V-32	1.71	3.23
V-33	1.56	3.05
V-34	.64	1.55
V-35	.57	.85
V-36	.59	.89
ROLL	0.00	0.00
PIT	.01	0.00
HEAV	6.11	12.10

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PROJECT 1566C

NOV 21 SEGMENT NUMBER 4 FILE NAME HEAV2
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	0.00	0.00
H-11	.19	.19
H-12	-.17	-.17
V-11	.39	.59
V-12	.20	.40
V-13	.18	.37
RV-1	0.00	0.00
HV-1	0.00	0.00
R-21	.37	.49
R-22	0.00	-.10
H-21	-.18	.18
H-22	-.28	-.09
H-23	-.10	-.10
V-21	1.37	2.11
V-22	.74	1.39
V-23	1.31	2.43
V-25	.12	-.12
R-31	-.04	-.41
R-32	-.19	-.19
H-31	-.31	0.00
H-32	0.00	-.09
H-33	.29	.59
V-31	.97	1.78
V-32	1.97	3.63
V-33	1.52	3.05
V-34	.57	1.02
V-35	.57	.85
V-36	.89	.89
ROLL	-.09	-.18
PIT	-.07	-.07
HEAV	8.62	14.64

NOV 21 SEGMENT NUMBER 4 FILE NAME HEAV1
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	.18	.54
H-11	-.95	-.95
H-12	.17	.52
V-11	-1.18	-1.37
V-12	-.80	-.80
V-13	.55	.55
RV-1	-.49	-.49
HV-1	-.28	-.42
R-21	.08	-.29
R-22	-.20	-.20
H-21	-.09	-.18
H-22	.28	.28
H-23	0.00	.20
V-21	-3.39	-3.48
V-22	-1.57	-1.76
V-23	-4.30	-5.33
V-25	1.50	1.00
R-31	-.21	.25
R-32	-.39	-.58
H-31	.21	.10
H-32	.09	.26
H-33	-.98	-1.38
V-31	-3.19	-4.16
V-32	-6.35	-7.51
V-33	-5.31	-7.23
V-34	-2.19	-2.86
V-35	-1.14	-1.42
V-36	-1.19	-1.78
ROLL	.27	.14
PIT	-.23	-.01
HEAV	-6.33	-14.32

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 21 SEGMENT NUMBER 4 FILE NAME ROLL1
CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	1.25	.89
H-11	1.90	1.90
H-12	3.52	3.87
V-11	.78	.59
V-12	1.00	.60
V-13	-1.37	-1.55
RV-1	-2.21	-1.96
HV-1	-.42	-.70
R-21	-.20	-.49
R-22	.20	.40
H-21	.45	.99
H-22	.38	1.32
H-23	-1.00	-1.20
V-21	-4.58	-6.59
V-22	-1.57	-2.68
V-23	-2.71	-5.24
V-25	-1.25	-1.25
R-31	-.25	-.58
R-32	.68	.58
H-31	2.88	5.97
H-32	2.65	6.17
H-33	-.98	-.88
V-31	-1.78	-3.68
V-32	-9.68	-18.99
V-33	-8.13	-14.96
V-34	-1.92	-4.15
V-35	-2.27	-4.26
V-36	-4.45	-6.53
ROLL	5.18	9.85
PIT	-.28	-.22
HEAV	-.47	-2.08

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 21 SEGMENT NUMBER 4 FILE NAME ROLL2
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	- .54	- .54
H-11	0.00	0.00
H-12	- .34	- .34
V-11	.20	.20
V-12	.40	.30
V-13	.18	.18
RV-1	.74	.74
HV-1	.14	.14
~~R-21~~	~~- .16~~	~~0.00~~
R-22	- .30	- .30
H-21	0.00	- .18
H-22	- .66	- .47
H-23	2.20	2.20
V-21	3.66	3.75
V-22	2.49	2.59
V-23	2.34	2.43
V-25	- .50	.25
R-31	1.03	1.37
R-32	0.00	0.00
H-31	- .41	- .51
H-32	- .35	- .71
H-33	1.18	.98
V-31	-2.22	-2.27
V-32	10.28	10.08
V-33	6.25	6.29
V-34	3.81	4.26
V-35	1.14	1.14
V-36	1.78	1.78
ROLL	-3.30	-3.30
PIT	- .07	- .08
HEAV	1.44	1.62

NOV 21 SEGMENT NUMBER 4 FILE NAME ROLL3
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	-.18	-.27
H-11	-.38	-.19
H-12	-.34	-.69
V-11	-.20	1.08
V-12	-.20	1.40
V-13	-.37	.18
RV-1	.37	.61
HV-1	.14	.28
R-21	-.57	.33
R-22	-.40	-.40
H-21	-1.44	-.99
H-22	-2.74	-1.04
H-23	1.00	2.20
V-21	1.37	4.85
V-22	.74	5.08
V-23	1.59	4.77
V-25	.75	-4.62
R-31	.66	.46
R-32	-.39	-.58
H-31	-2.47	-.21
H-32	-.88	.35
H-33	-.39	.29
V-31	-1.73	-.65
V-32	7.71	12.91
V-33	4.45	7.15
V-34	3.77	7.24
V-35	.57	-.28
V-36	1.78	.59
ROLL	-3.30	-7.37
PIT	.10	.09
HEAV	1.44	4.51

NOV 21 SEGMENT NUMBER 4 FILE NAME PIT1
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)
R-11	3.22
H-11	-3.81
H-12	-3.78
V-11	-4.12
V-12	-4.20
V-13	-7.67
RV-1	3.43
HV-1	6.28
R-21	-1.31
R-22	.20
H-21	1.08
H-22	1.70
H-23	.20
V-21	-10.62
V-22	-5.64
V-23	-13.65
V-25	.75
R-31	-1.86
R-32	-.58
H-31	1.85
H-32	4.59
H-33	-.98
V-31	-11.30
V-32	-18.10
V-33	-10.43
V-34	-7.99
V-35	-5.68
V-36	-6.53
ROLL	.92
PIT	-1.94
HEAV	2.14

ARCTEC CANADA LTD.

PROJECT 1566C

NOV 21 SEGMENT NUMBER 4 FILE NAME PITZ
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)
R-11	1.07
H-11	-2.67
H-12	-1.03
V-11	-1.08
V-12	-2.40
V-13	-4.75
RV-1	1.47
HV-1	1.96
R-21	2.87
R-22	.40
H-21	-1.44
H-22	.38
H-23	.80
V-21	-24.91
V-22	-5.45
V-23	-20.20
V-25	1.00
R-31	6.87
R-32	.39
H-31	4.53
H-32	3.44
H-33	-3.93
V-31	-18.92
V-32	-21.88
V-33	-18.98
V-34	-9.31
V-35	-16.20
V-36	-10.68
ROLL	.09
PIT	-3.40
HEAV	3.70

NOV 21 SEGMENT NUMBER 4 FILE NAME PIT3
 CALIBRATION POSITION 1

TRANSDUCER	READING (N)	
R-11	-1.07	-1.25
H-11	1.71	1.71
H-12	1.55	1.38
V-11	5.29	5.29
V-12	3.60	3.60
V-13	0.00	.18
RV-1	-1.72	-1.72
HV-1	-1.12	-1.12
R-21	1.02	.53
R-22	-.20	.20
H-21	-1.44	-1.62
H-22	.57	.57
H-23	.80	1.00
V-21	5.86	5.49
V-22	4.44	4.44
V-23	6.92	7.11
V-25	-11.86	-8.49
R-31	.95	.17
R-32	.39	.19
H-31	-.41	1.24
H-32	-1.15	0.00
H-33	.20	1.38
V-31	4.00	3.03
V-32	12.25	7.26
V-33	10.66	7.11
V-34	5.99	1.81
V-35	.85	1.42
V-36	0.00	-.59
ROLL	-.05	-.55
PIT	2.06	1.36
HEAV	-10.28	-14.95

APPENDIX I.2

TRANSDUCER STATISTICS FROM OPEN WATER TOW TESTS (MODEL FIXED TO CARRIAGE)

The mean standard deviation maximum and minimum values of each transducer during the three open water tests are given here. In order listed here the tests are: OW3 ($v = 0.19$ m/s); OW4 ($v = 0.43$ m/s) and OW5 ($v = 0.64$ m/s). The statistics were only performed on the constant speed section of each test. For further information regarding the tests see Section 6, Volume I.

Open Water Test: OW
 Run: 3
 Speed: 0.19 m/s
 Date Digitized: 21 Nov 1986
 Digitizing Rate: 61 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R11	-.18	.18	.08	.09
RV1	-.28	0.00	-.04	.10
H11	-.56	0.00	-.21	.09
H12	-.69	0.00	-.42	.12

Date Digitized: 21 Nov 1986
 Digitizing Rate: 61 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V11	-.13	.26	.07	.06
V12	0.00	.20	.12	.10
V13	0.00	.18	.14	.08
HV1	.20	.39	.30	.10

Date Digitized: 21 Nov 1986
 Digitizing Rate: 61 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R21	0.00	.66	.26	.12
R22	0.00	.20	.07	.10

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
H21	-1.44	1.08	.35	.28
H22	-.38	.58	-.03	.16
H23	-.20	0.00	-.07	.09

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V21	-.55	.55	.20	.16
V22	-.19	.37	-0.00	.12
V23	-.56	.37	.06	.16
V25	.25	1.25	.78	.32

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R31	-1.16	.91	-.37	.29
R32	-.39	0.00	-.23	.09
V35	-.13	.15	.15	.03
V36	0.00	.59	.05	.16

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
H31	-1.03	.82	.21	.19
H32	-.71	.35	-.23	.11
H33	-.20	.20	0.00	.02

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V31	-.54	.76	.25	.22
V32	-.31	.20	-.04	.11
V33	-.54	.47	-.01	.15
V34	-.35	.55	.21	.17

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 15.51 to 62.31 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
FORCE	-475.74	536.56	-8.82	69.83
SPEED	.16	.23	.19	.01
POS	-.98	-.13	-.56	.24

Open Water Test: OW
 Run: 4
 Speed: 0.43 m/s
 Date Digitized: 21 Nov 1986
 Digitizing Rate: 62 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R11	.18	.36	.25	.09
RV1	0.00	.28	.16	.14
H11	-.23	.14	-.01	.09
H12	-.34	0.00	-.23	.09

Date Digitized: 21 Nov 1986
 Digitizing Rate: 62 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V11	0.00	.39	.21	.11
V12	.20	.60	.37	.11
V13	-.19	.36	.13	.10
HV1	0.00	.20	.12	.10

Date Digitized: 21 Nov 1986
 Digitizing Rate: 62 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R21	.18	.93	.51	.15
R22	0.00	0.00	0.00	0.00

Date Digitized: 21 Nov 1986
Digitizing Rate: 62 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
H21	-.58	1.59	.55	.39
H22	-.38	.58	.09	.16
H23	0.00	.20	.01	.03

Date Digitized: 21 Nov 1986
Digitizing Rate: 62 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V21	-.55	.75	.15	.23
V22	-.19	.19	.06	.09
V23	-.56	.38	-.04	.16
V25	0.00	1.00	.44	.21

Date Digitized: 21 Nov 1986
Digitizing Rate: 62 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R31	-.82	1.17	.13	.40
R32	-.19	.19	.02	.10
V35	-.28	0.00	-.05	.10
V36	-.57	.02	-.09	.23

Date Digitized: 21 Nov 1986
Digitizing Rate: 62 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
H31	-.68	.96	.13	.31
H32	-.71	.18	-.29	.19
H33	-.22	.18	.02	.08

Date Digitized: 21 Nov 1986
Digitizing Rate: 62 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V31	-.53	.55	-.05	.26
V32	-.47	-.07	-.35	.08
V33	-.64	.69	-.15	.35
V34	-.53	.30	-.15	.20

Date Digitized: 21 Nov 1986
Digitizing Rate: 62 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 33.61 to 58.37 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
FORCE	-300.82	320.73	-17.93	120.79
SPEED	.37	.46	.43	.01
POS	-2.00	-.14	-.65	.30

Open Water Test: OW
 Run: 5
 Speed: 0.64 m/s
 Date Digitized: 21 Nov 1986
 Digitizing Rate: 61 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R11	0.00	.54	.17	.11
RV1	.18	.75	.56	.14
H11	-.67	.26	-.23	.21
H12	-.69	.17	-.37	.15

Date Digitized: 21 Nov 1986
 Digitizing Rate: 61 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V11	.39	.98	.73	.15
V12	.40	1.40	1.08	.17
V13	-.18	.37	.09	.14
HV1	.20	.39	.33	.09

Date Digitized: 21 Nov 1986
 Digitizing Rate: 61 Hz/Channel
 Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R21	.49	1.64	1.03	.22
R22	0.00	.20	.10	.10

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
H21	-.43	2.64	1.22	.55
H22	-.41	.94	.13	.24
H23	-.04	.55	.24	.11

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V21	-.55	1.11	.35	.29
V22	-.37	.37	-.04	.13
V23	-.56	.37	.02	.19
V25	0.00	1.75	.77	.43

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
R31	-.70	2.20	.50	.52
R32	-.19	.39	.05	.11
V35	-.28	.28	0.00	.11
V36	0.00	.59	.01	.09

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
H31	-.81	1.25	.17	.42
H32	-.84	.21	-.43	.18
H33	-.20	.20	-.01	.07

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
V31	-1.41	.54	-.15	.36
V32	-.95	-.35	-.63	.12
V33	-.33	-.10	-.25	.06
V34	-1.37	-.31	-.68	.24

Date Digitized: 21 Nov 1986
Digitizing Rate: 61 Hz/Channel
Filter Frequency: 0 Hz

STATISTICS

For Interval from 11.67 to 42.95 Seconds

CHANNEL	MINIMUM	MAXIMUM	MEAN VALUE	STANDARD DEV
FORCE	-530.25	351.80	-32.58	174.19
SPEED	.54	.69	.64	.01
POS	-2.06	-.18	-1.12	.55

APPENDIX J

RESULTS OF THE ICE TESTS

J.1 ICE SHEET #1 TEST RUNS

This appendix contains the results of the tests conducted in ice sheet #1. During this test only segment 2 was instrumented. The results are presented in graph form against time. Five graphs for each test are presented. In order they are: segment forces, which is the normal force and friction force superimposed on one graph; x position of the force; z position of the force; friction direction of the force and friction coefficient. The definition of the friction direction is given in Section 3, Volume I. The data for the graphs was calculated from the transducer measurement using the data reduction algorithm outlined in Section 3, Volume 1. Each data point on the graph was derived from the average of two consecutive transducer measurements. The data points are approximately 0.5 seconds apart. Discontinuities in the graphs (as discussed in Section 7, Volume I) occur when the forces are too low to be accurately traced by the segments. In cases where less than 20 points were resolved by the algorithm only the segment forces plot has been given. In Table J.1 the particulars of each test are given. The graphs follow in the order in which they are given in the Table. At the end of each group of five graphs the statistics of the graphed variables are given over the active time period of the test.

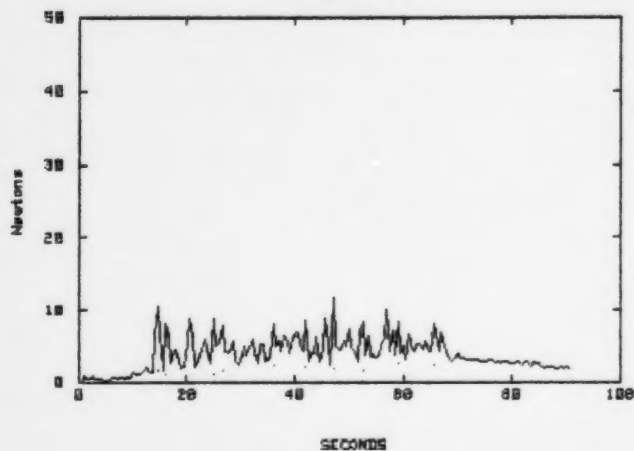
TABLE J.1

ICE TESTS CONDUCTED DURING ICE SHEET #1

ICE SHEET	RUN	TYPE OF TEST	ICE THICKNESS mm	ICE STRENGTH kPa	MODEL SPEED m/s	FULL SCALE SPEED knots	LENGTH OF TEST RUN L/L_{WL}
1	NS2	NS	20	35	0.15	1.3	1.97
1	NS3	NS	20	35	0.43	3.7	2.19
1	CW1	CW	20	35	0.15	1.3	2.19
1	CW2	CW	20	35	0.45	3.9	3.28
1	CW3	CW	20	35	0.10	0.9	2.19
1	CW4	CW	20	35	0.60	5.2	2.19
1	SS1	SS	20	35	0.15	1.3	2.19
1	SS2	SS	20	35	0.45	3.9	2.19

Note: $L_{WL} = 4.575$ m

NS RUN 2 SEGMENT 2
SEGMENT FORCES



STATISTICS FOR INTERVAL FROM 16.00 TO 70.00 Seconds

SAMPLES CALCULATED EVERY .497 SECS

TEST NS RUN 2 DATE:

SEGMENT 2

AVERAGE NORMAL FORCE 5.065 STANDARD DEVIATION 1.867

AVERAGE X POSITION 1.783 STANDARD DEVIATION .057

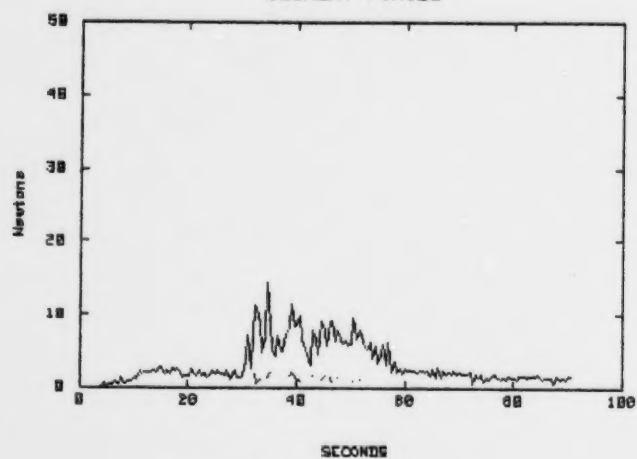
AVERAGE Z POSITION .060 STANDARD DEVIATION .010

AVERAGE FRICTION COEFF .222 STANDARD DEVIATION .062

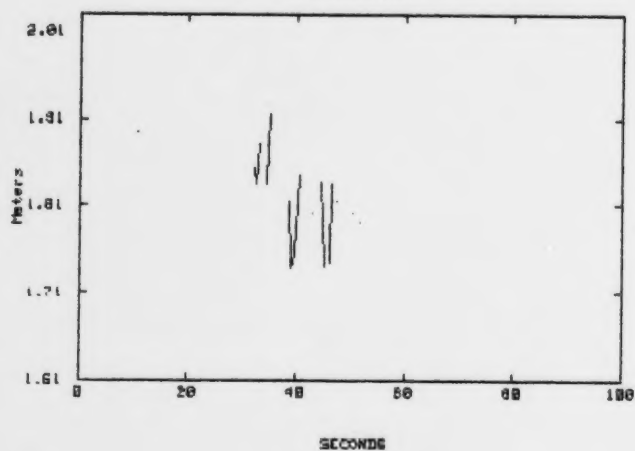
PROJECTED FRICT. DIR. -114.898 STANDARD DEVIATION 12.111

NUMBER OF DATA POINTS USED IN STATISTICS: 9

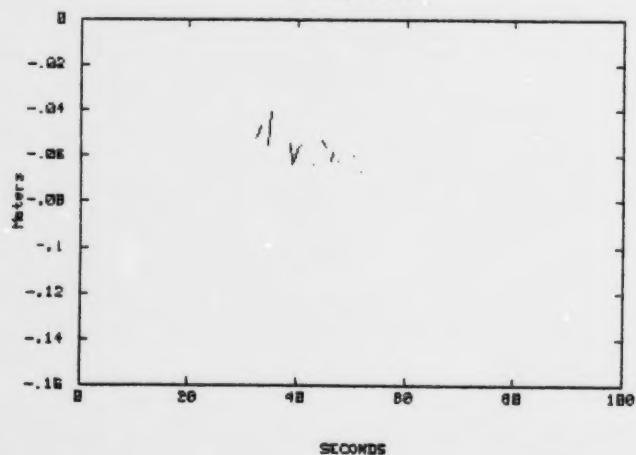
NS RUN 3 SEGMENT 2
SEGMENT FORCES



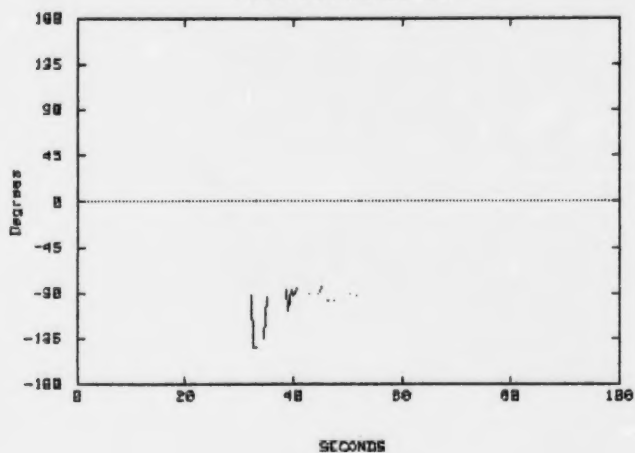
NS RUN 3 SEGMENT 2
X POSITION



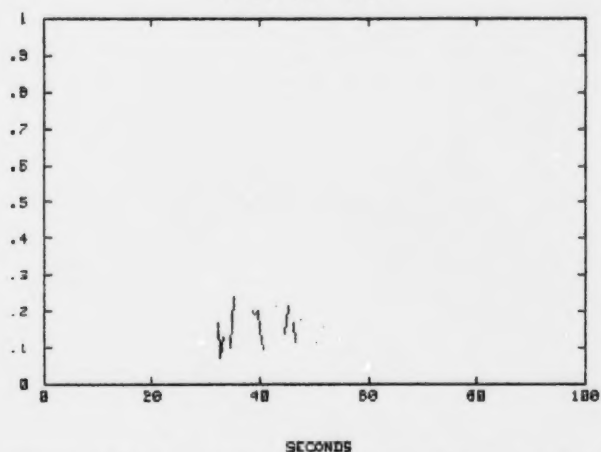
NS RUN 3 SEGMENT 2
Z POSITION



NS RUN 3 SEGMENT 2
FRICTION DIRECTION



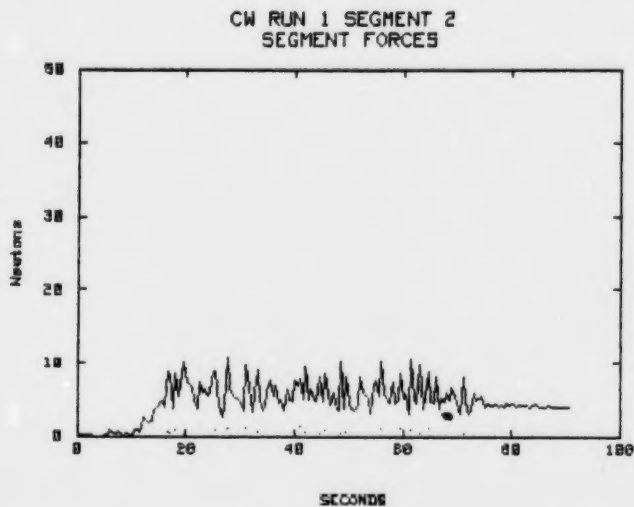
NS RUN 3 SEGMENT 2
FRICTION COEFF



STATISTICS FOR INTERVAL FROM 32.00 TO 60.00 Seconds
 SAMPLES CALCULATED EVERY .497 SECS
 TEST NS RUN 3 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	6.642	STANDARD DEVIATION	2.468
AVERAGE X POSITION	1.813	STANDARD DEVIATION	.047
AVERAGE Z POSITION	.056	STANDARD DEVIATION	.006
AVERAGE FRICTION COEFF	.159	STANDARD DEVIATION	.046
PROJECTED FRICT. DIR.	-100.182	STANDARD DEVIATION	18.865

NUMBER OF DATA POINTS USED IN STATISTICS: 18



STATISTICS FOR INTERVAL FROM 18.00 TO 72.00 Seconds

SAMPLES CALCULATED EVERY .497 SECS

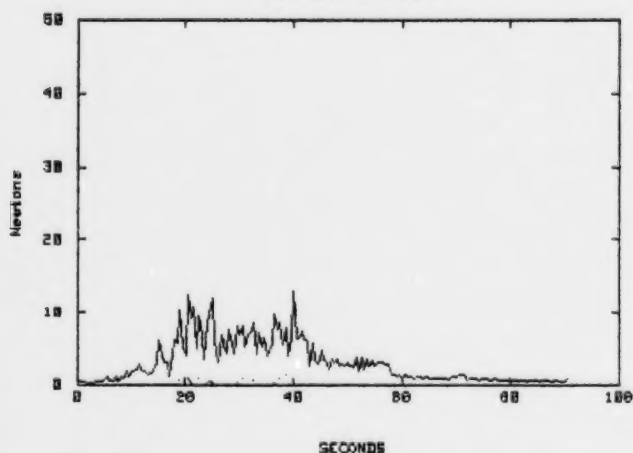
TEST CW RUN 1 DATE:

SEGMENT 2

AVERAGE NORMAL FORCE	6.038	STANDARD DEVIATION	1.906
AVERAGE X POSITION	1.739	STANDARD DEVIATION	.066
AVERAGE Z POSITION	.048	STANDARD DEVIATION	.009
AVERAGE FRICTION COEFF	.098	STANDARD DEVIATION	.038
PROJECTED FRICT. DIR.	-62.016	STANDARD DEVIATION	58.386

NUMBER OF DATA POINTS USED IN STATISTICS: 18

CW RUN 2 SEGMENT 2
SEGMENT FORCES



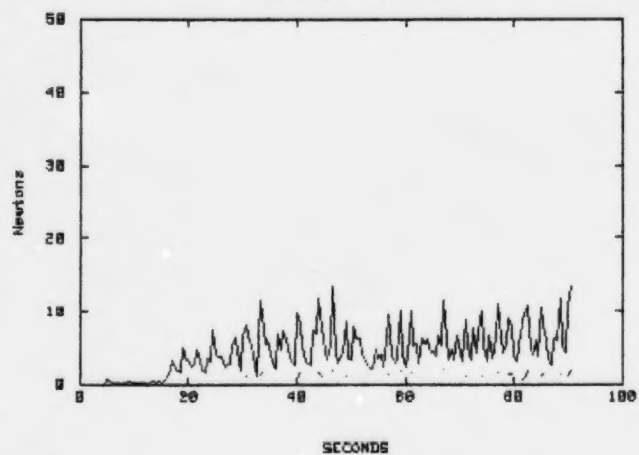
STATISTICS FOR INTERVAL FROM 19.00 TO 43.00 Seconds
SAMPLES CALCULATED EVERY .497 SECS

TEST CW RUN 2 DATE:
SEGMENT 2

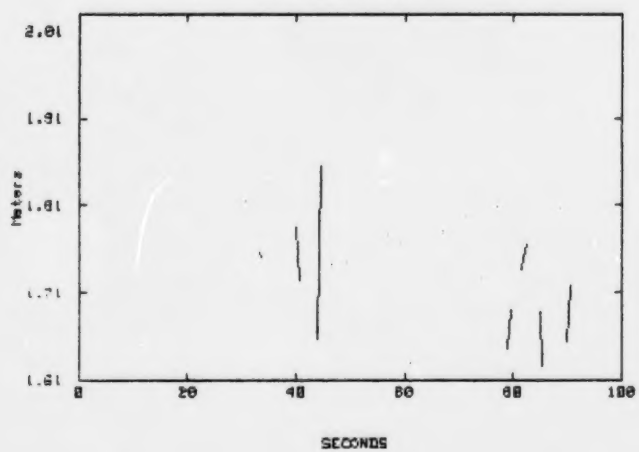
AVERAGE NORMAL FORCE	6.998	STANDARD DEVIATION	2.327
AVERAGE X POSITION	1.810	STANDARD DEVIATION	.033
AVERAGE Z POSITION	.051	STANDARD DEVIATION	.004
AVERAGE FRICTION COEFF	.067	STANDARD DEVIATION	.050
PROJECTED FRICT. DIR.	-5.608	STANDARD DEVIATION	108.560

NUMBER OF DATA POINTS USED IN STATISTICS: 15

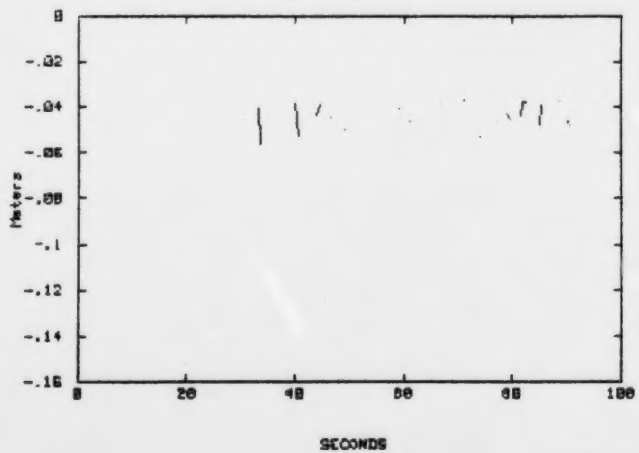
CW RUN 3 SEGMENT 2
SEGMENT FORCES



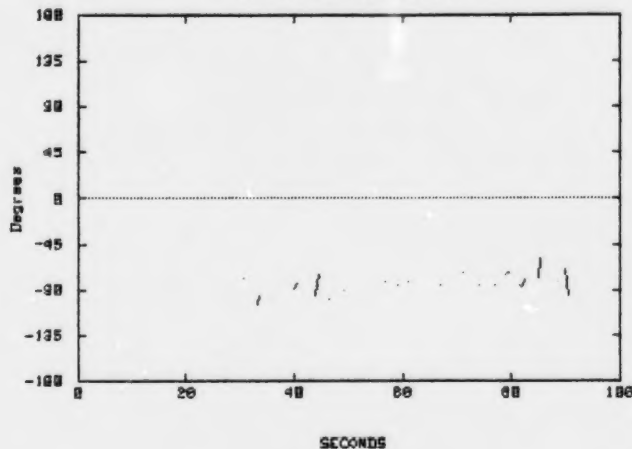
CW RUN 3 SEGMENT 2
X POSITION



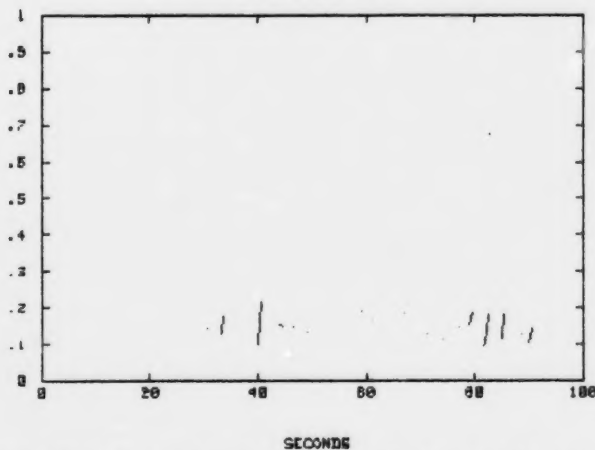
CW RUN 3 SEGMENT 2
Z POSITION



CW RUN 3 SEGMENT 2
FRICTION DIRECTION

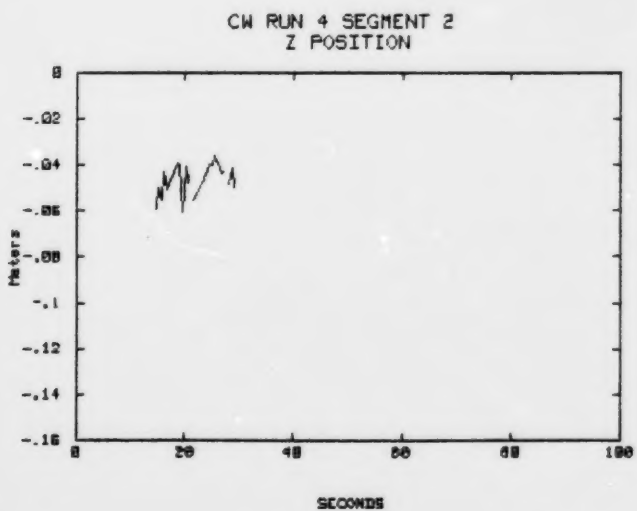
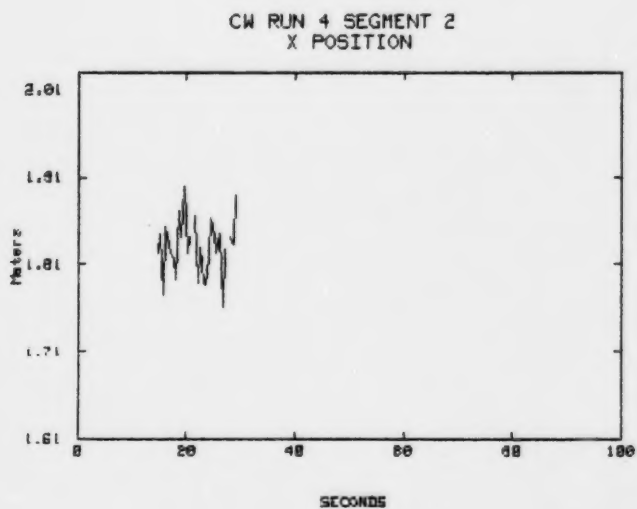
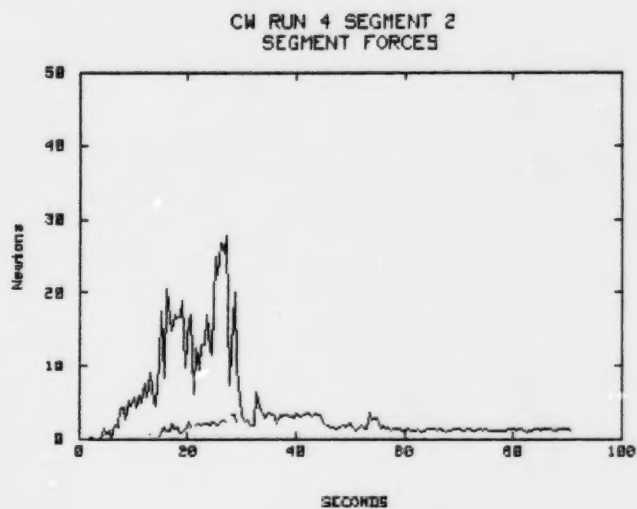


CW RUN 3 SEGMENT 2
FRICTION COEFF

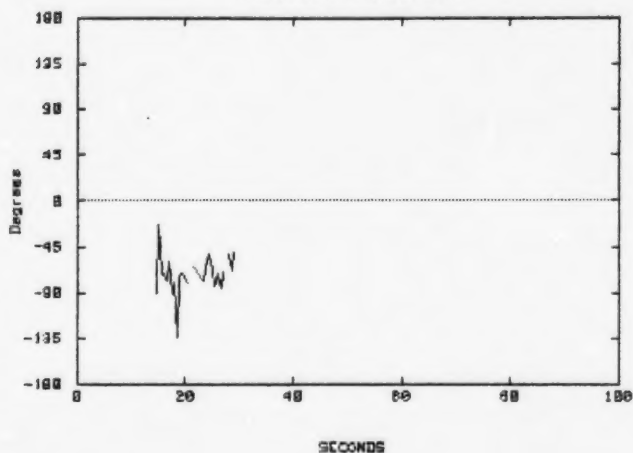


STATISTICS FOR INTERVAL FROM 25.00 TO 100.00 Seconds
 SAMPLES CALCULATED EVERY .497 SECS
 TEST CW RUN 3 DATE:
 SEGMENT 2

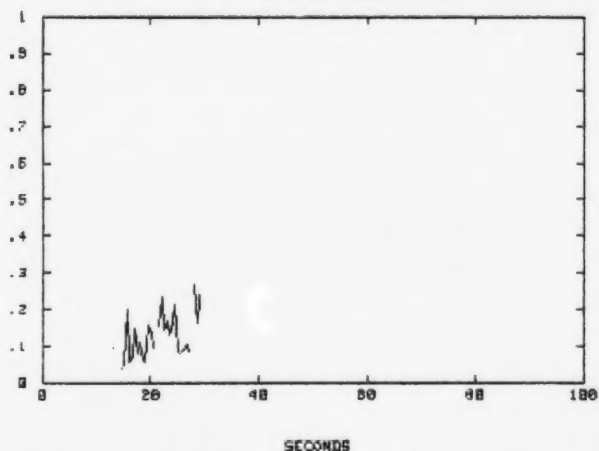
AVERAGE NORMAL FORCE	5.706	STANDARD DEVIATION	2.629
AVERAGE X POSITION	1.739	STANDARD DEVIATION	.060
AVERAGE Z POSITION	.044	STANDARD DEVIATION	.005
AVERAGE FRICTION COEFF	.147	STANDARD DEVIATION	.031
PROJECTED FRICT. DIR.	-83.510	STANDARD DEVIATION	9.682
NUMBER OF DATA POINTS USED IN STATISTICS:		26	



CW RUN 4 SEGMENT 2
FRICTION DIRECTION



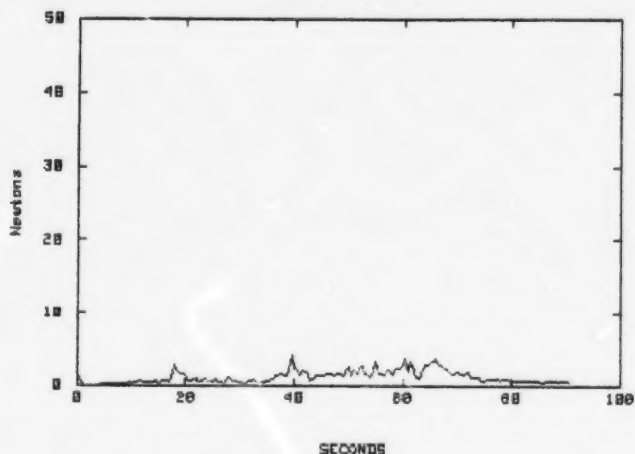
CW RUN 4 SEGMENT 2
FRICTION COEFF



STATISTICS FOR INTERVAL FROM 13.00 TO 30.00 Seconds
 SAMPLES CALCULATED EVERY .497 SECS
 TEST CW RUN 4 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	14.613	STANDARD DEVIATION	6.172
AVERAGE X POSITION	1.831	STANDARD DEVIATION	.032
AVERAGE Z POSITION	.047	STANDARD DEVIATION	.008
AVERAGE FRICTION COEFF	.128	STANDARD DEVIATION	.060
PROJECTED FRICT. DIR.	-66.814	STANDARD DEVIATION	33.220
NUMBER OF DATA POINTS USED IN STATISTICS:		29	

SS RUN 1 SEGMENT 2
SEGMENT FORCES



STATISTICS FOR INTERVAL FROM 0.00 TO 100.00 Seconds

SAMPLES CALCULATED EVERY .497 SECS

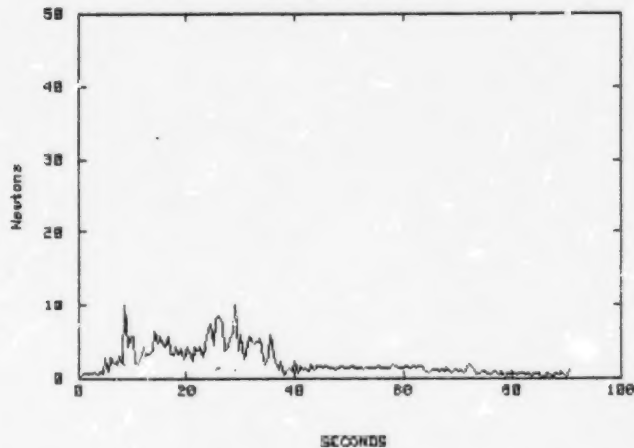
TEST SS RUN 1 DATE:

SEGMENT 2

AVERAGE NORMAL FORCE	2.709	STANDARD DEVIATION	.592
AVERAGE X POSITION	0.000	STANDARD DEVIATION	0.000
AVERAGE Z POSITION	0.000	STANDARD DEVIATION	0.000
AVERAGE FRICTION COEFF	0.000	STANDARD DEVIATION	0.000
PROJECTED FRICT. DIR.	0.000	STANDARD DEVIATION	0.000

NUMBER OF DATA POINTS USED IN STATISTICS: 0

SS RUN 2 SEGMENT 2
SEGMENT FORCES



STATISTICS FOR INTERVAL FROM 5.00 TO 38.00 Seconds
 SAMPLES CALCULATED EVERY .497 SECS
 TEST SS RUN 2 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	4.463	STANDARD DEVIATION	1.866
AVERAGE X POSITION	1.834	STANDARD DEVIATION	.031
AVERAGE Z POSITION	.056	STANDARD DEVIATION	.005
AVERAGE FRICTION COEFF	.159	STANDARD DEVIATION	.032
PROJECTED FRICT. DIR.	-41.108	STANDARD DEVIATION	110.964
NUMBER OF DATA POINTS USED IN STATISTICS:		4	



J.2 ICE SHEET #2 TEST RUNS

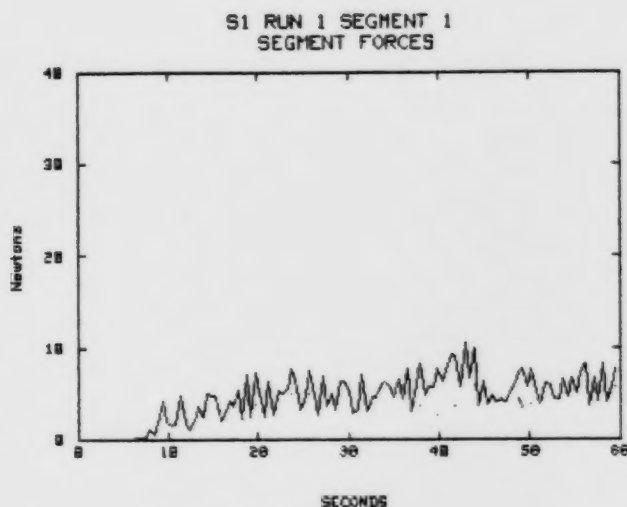
This appendix contains the results of the tests conducted in ice sheet #2. The results are presented in graph form against time. Five graphs for each segment in each test are presented. In order they are: friction direction of the force; friction coefficient; segment forces, which is the normal force and friction force superimposed on one graph; x position of the force; and z position of the force. The definition of the friction direction is given in Section 3, Volume I. The data for the graphs was calculated from the transducer measurement using the data reduction algorithm outlined in Section 3, Volume I. Each data point on the graph was derived from the average of two consecutive transducer measurements. The data points are approximately 0.5 seconds apart. Discontinuities in the graphs (as discussed in Section 7, Volume I) occur when the forces are too low to be accurately traced by the segments. In cases where less than 20 points were resolved by the algorithm only the segment forces plot has been given. In Table J.2 the particulars of each test are given. The graphs for each test follow in the order in which they are given in the Table. For each test the segments are given in order 1 to 3. Included in each group of five graphs are the statistics of the graphed variables are given over the active time period of the test.

TABLE J.2

ICE TESTS CONDUCTED DURING ICE SHEET #2

ICE SHEET	RUN	TYPE OF TEST	ICE THICKNESS mm	ICE STRENGTH kPa	MODEL SPEED m/s	FULL SCALE SPEED knots	LENGTH OF TEST RUN L/L_{WL}
2	S11	NS	27	25	0.14	1.2	1.54
2	S12	NS	27	25	0.45	3.9	2.65
2	CW5	CW	27	25	0.18	1.6	1.44
2	CW6	CW	27	25	0.45	3.9	2.85
2	CW7	CW	27	25	0.66	5.7	4.37

Note: $L_{WL} = 4.575$ m



STATISTICS FOR INTERVAL FROM 19.00 TO 60.00 Seconds

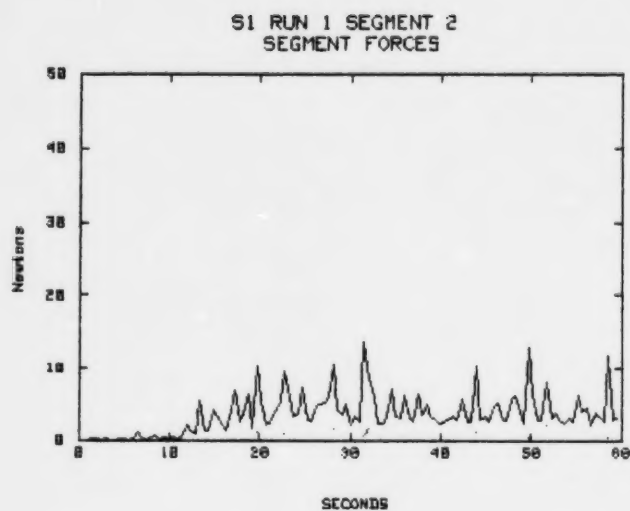
SAMPLES CALCULATED EVERY .488 SECS

TEST S1 RUN 1 DATE:

SEGMENT 1

AVERAGE NORMAL FORCE	5.510	STANDARD DEVIATION	1.741
AVERAGE X POSITION	2.256	STANDARD DEVIATION	.091
AVERAGE Z POSITION	.039	STANDARD DEVIATION	.006
AVERAGE FRICTION COEFF	.549	STANDARD DEVIATION	.195
PROJECTED FRICT. DIR.	-96.599	STANDARD DEVIATION	17.201

NUMBER OF DATA POINTS USED IN STATISTICS: 30

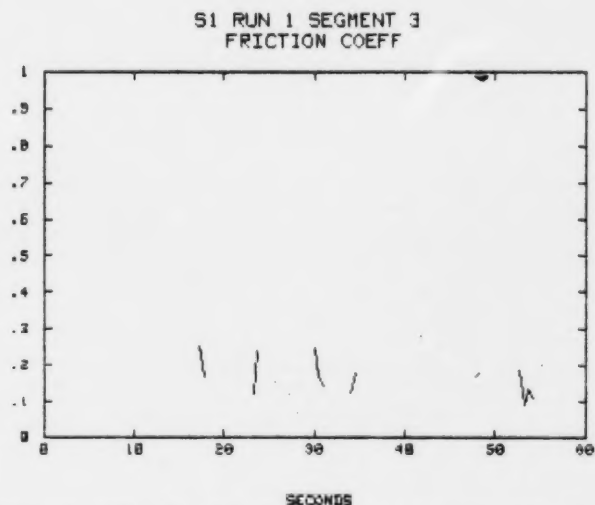
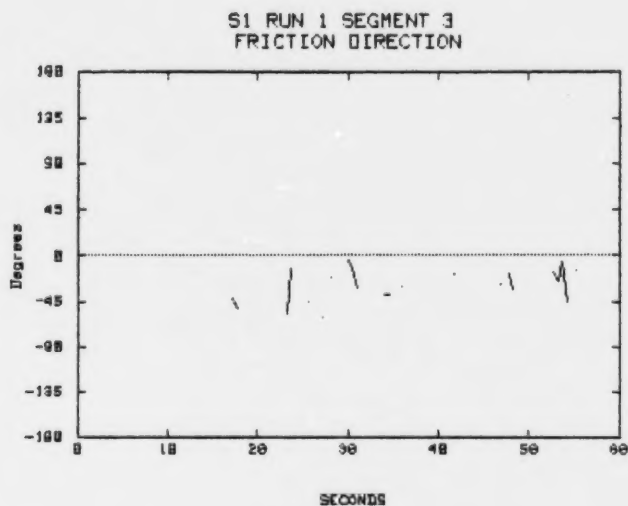


STATISTICS FOR INTERVAL FROM .52 TO 59.53 Seconds
 SAMPLES CALCULATED EVERY .488 SECS

TEST S1 RUN 1 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	4.545	STANDARD DEVIATION	2.477
AVERAGE X POSITION	1.810	STANDARD DEVIATION	.040
AVERAGE Z POSITION	.033	STANDARD DEVIATION	.007
AVERAGE FRICTION COEFF	.125	STANDARD DEVIATION	.075
PROJECTED FRICT. DIR.	29.494	STANDARD DEVIATION	50.638

NUMBER OF DATA POINTS USED IN STATISTICS: 9



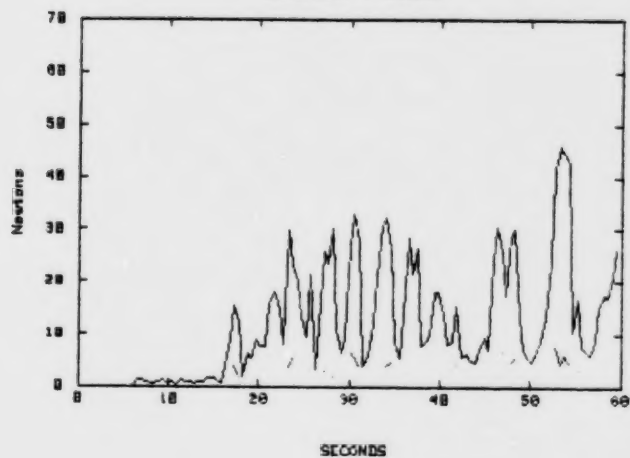
STATISTICS FOR INTERVAL FROM .52 TO 59.53 Seconds
 SAMPLES CALCULATED EVERY .488 SECS

TEST S1 RUN 1 DATE:
 SEGMENT 3

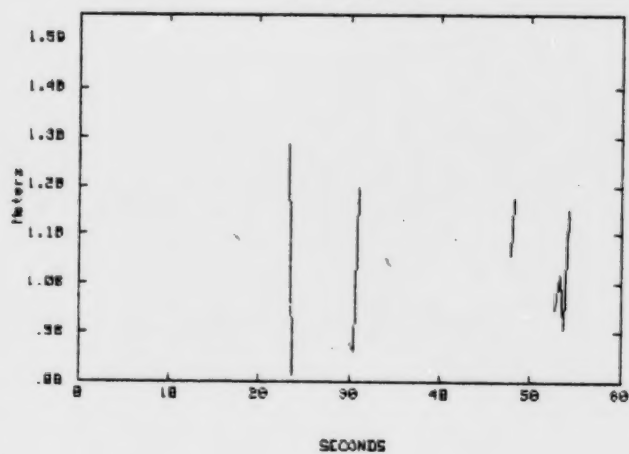
AVERAGE NORMAL FORCE	15.970	STANDARD DEVIATION	10.343
AVERAGE X POSITION	1.131	STANDARD DEVIATION	.133
AVERAGE Z POSITION	.044	STANDARD DEVIATION	.014
AVERAGE FRICTION COEFF	.173	STANDARD DEVIATION	.056
PROJECTED FRICT. DIR.	-29.709	STANDARD DEVIATION	16.029

NUMBER OF DATA POINTS USED IN STATISTICS: 22

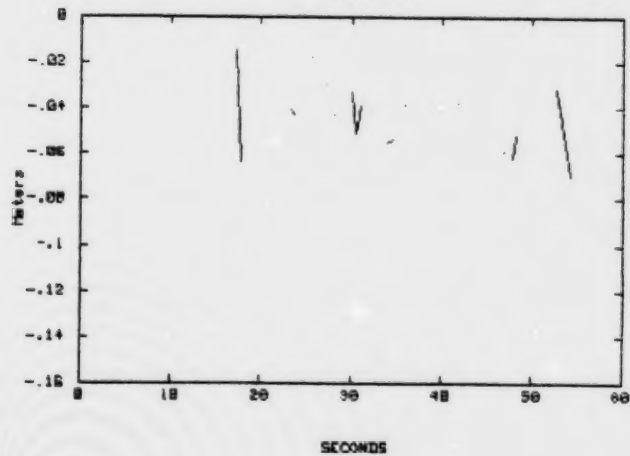
S1 RUN 1 SEGMENT 3
SEGMENT FORCES



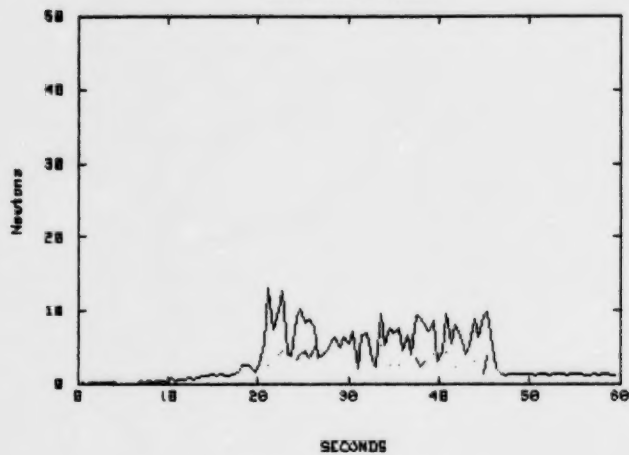
S1 RUN 1 SEGMENT 3
X POSITION



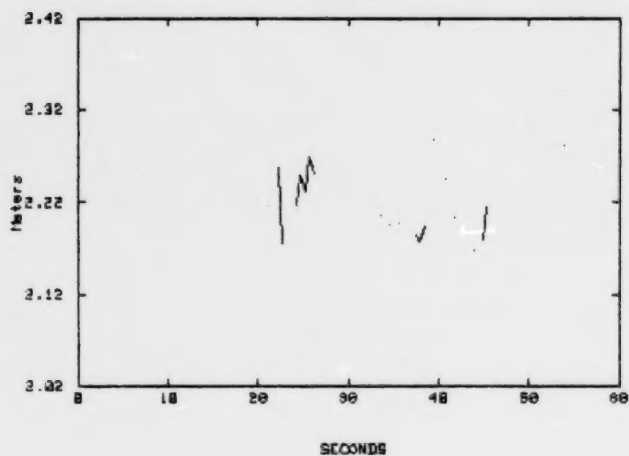
S1 RUN 1 SEGMENT 3
Z POSITION



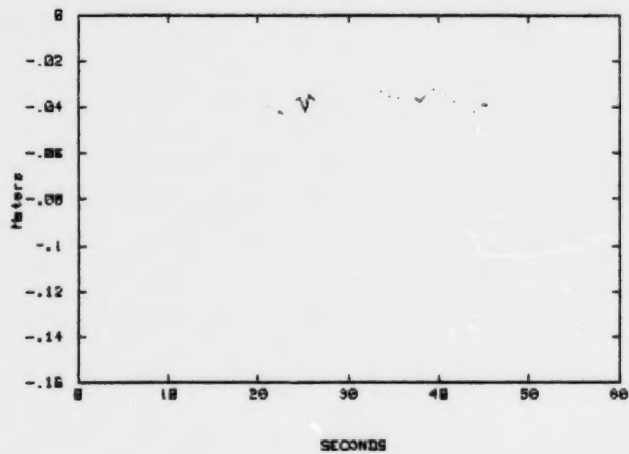
S1 RUN 2 SEGMENT 1
SEGMENT FORCES

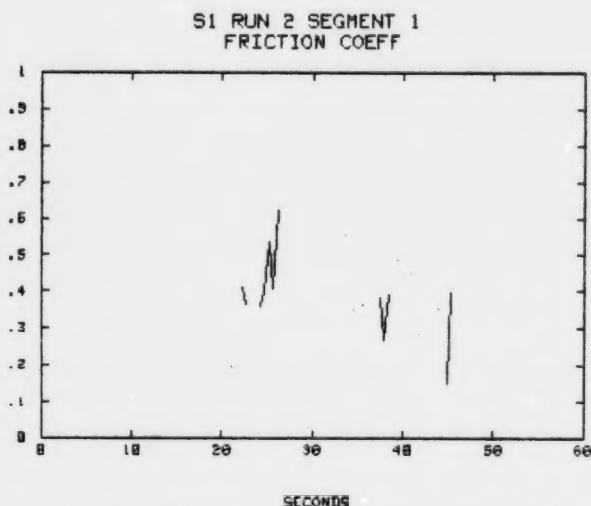
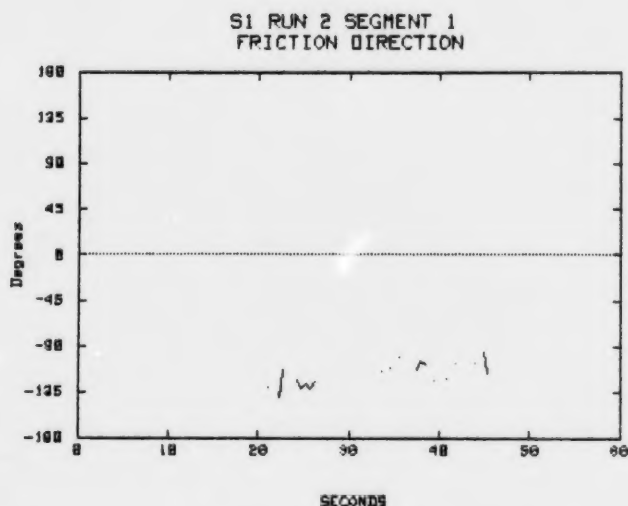


S1 RUN 2 SEGMENT 1
X POSITION



S1 RUN 2 SEGMENT 1
Z POSITION



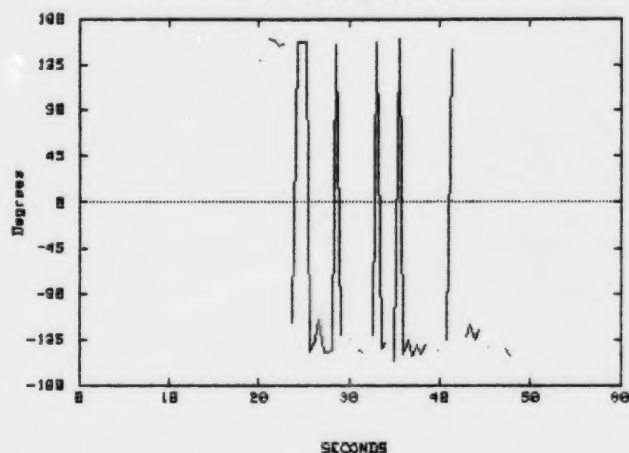


STATISTICS FOR INTERVAL FROM 21.00 TO 45.00 Seconds
SAMPLES CALCULATED EVERY .496 SECS

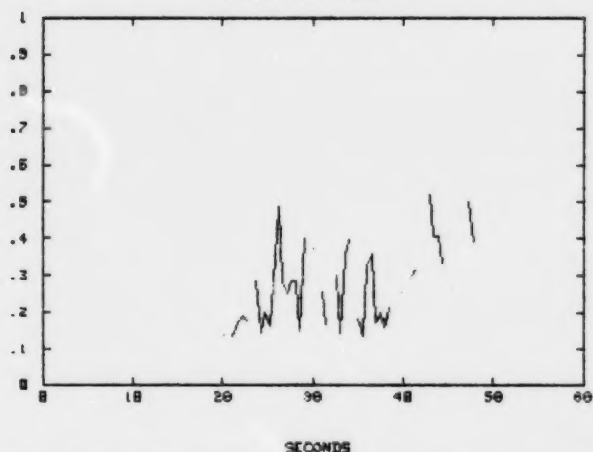
TEST S1 RUN 2 DATE:
SEGMENT 1

AVERAGE NORMAL FORCE	5.459	STANDARD DEVIATION	2.147
AVERAGE X POSITION	2.227	STANDARD DEVIATION	.042
AVERAGE Z POSITION	.039	STANDARD DEVIATION	.004
AVERAGE FRICTION COEFF	.375	STANDARD DEVIATION	.145
PROJECTED FRICT. DIR.	-97.472	STANDARD DEVIATION	58.190
NUMBER OF DATA POINTS USED IN STATISTICS:		22	

S1 RUN 2 SEGMENT 2
FRICTION DIRECTION



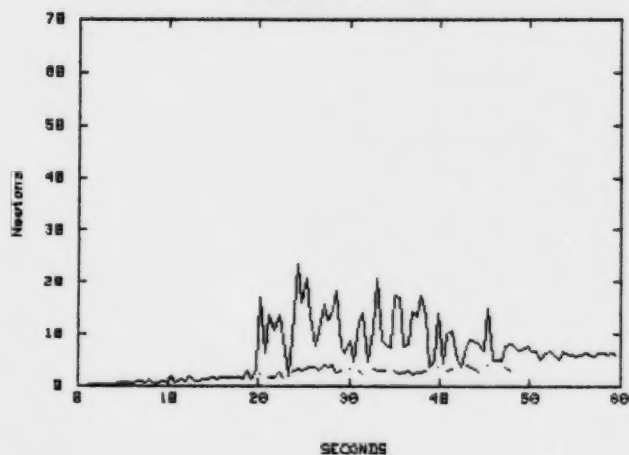
S1 RUN 2 SEGMENT 2
FRICTION COEFF



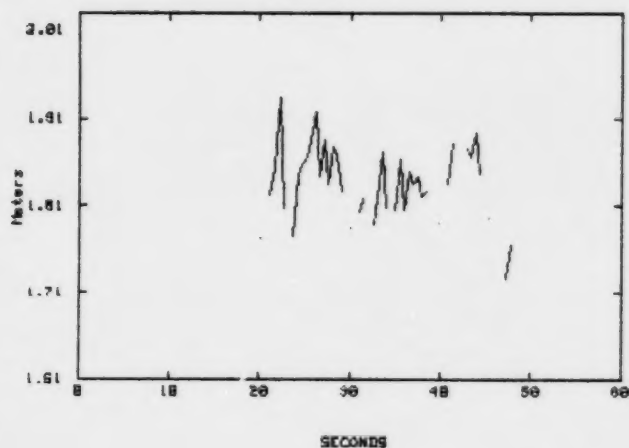
STATISTICS FOR INTERVAL FROM 21.00 TO 45.00 Seconds
 SAMPLES CALCULATED EVERY .488 SECS
 TEST S1 RUN 2 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	10.928	STANDARD DEVIATION	4.856
AVERAGE X POSITION	1.843	STANDARD DEVIATION	.036
AVERAGE Z POSITION	.051	STANDARD DEVIATION	.004
AVERAGE FRICTION COEFF	.268	STANDARD DEVIATION	.102
PROJECTED FRICT. DIR.	-52.876	STANDARD DEVIATION	134.092
NUMBER OF DATA POINTS USED IN STATISTICS:		38	

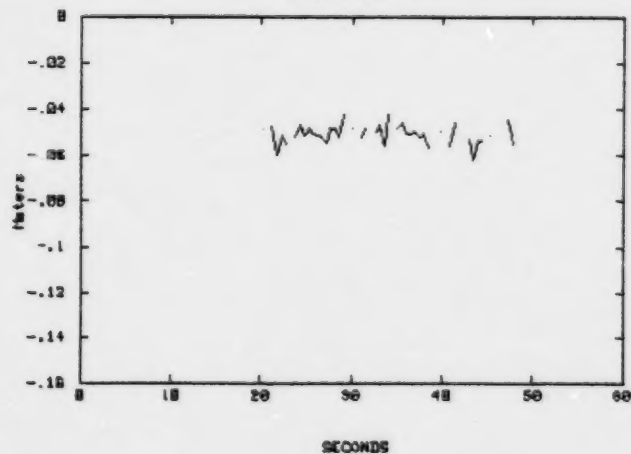
S1 RUN 2 SEGMENT 2
SEGMENT FORCES

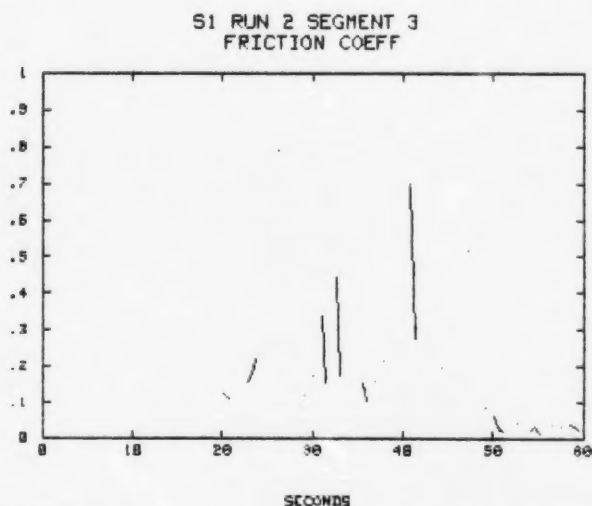
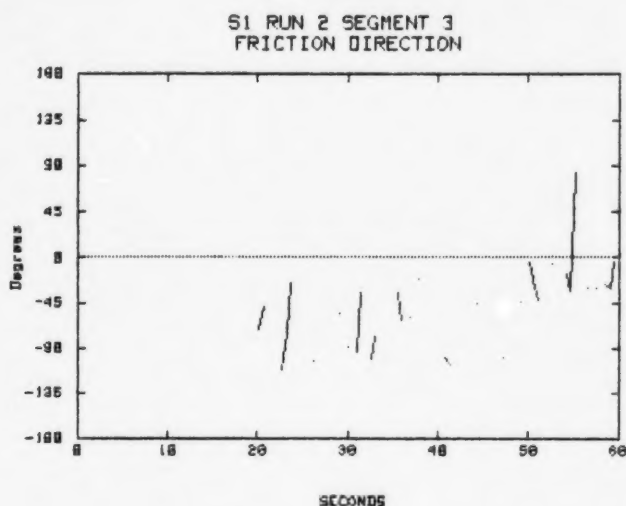


S1 RUN 2 SEGMENT 2
X POSITION



S1 RUN 2 SEGMENT 2
Z POSITION



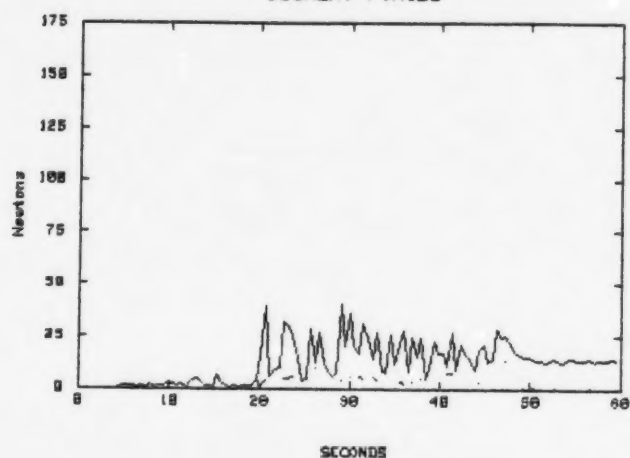


STATISTICS FOR INTERVAL FROM 21.00 TO 45.00 Seconds
SAMPLES CALCULATED EVERY .488 SECS

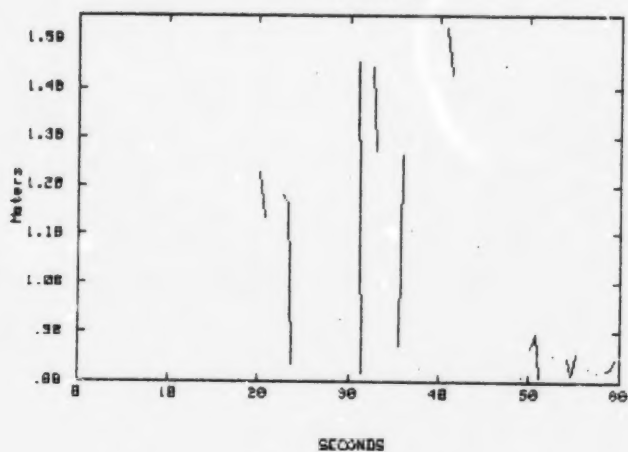
TEST S1 RUN 2 DATE:
SEGMENT 3

AVERAGE NORMAL FORCE	17.609	STANDARD DEVIATION	8.884
AVERAGE X POSITION	1.247	STANDARD DEVIATION	.235
AVERAGE Z POSITION	.030	STANDARD DEVIATION	.013
AVERAGE FRICTION COEFF	.267	STANDARD DEVIATION	.192
PROJECTED FRICT. DIR.	-70.221	STANDARD DEVIATION	29.040
NUMBER OF DATA POINTS USED IN STATISTICS:		17	

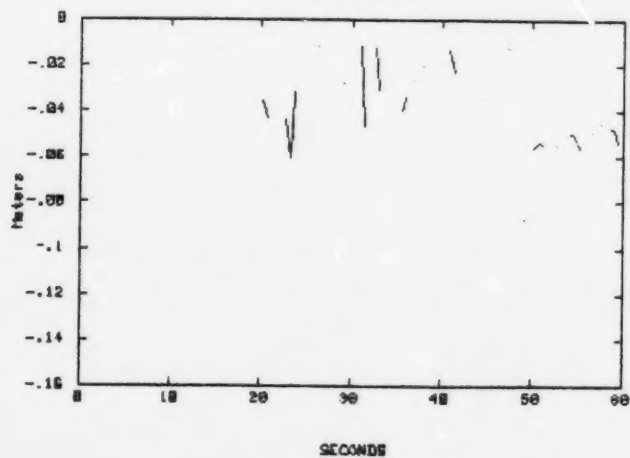
S1 RUN 2 SEGMENT 3
SEGMENT FORCES

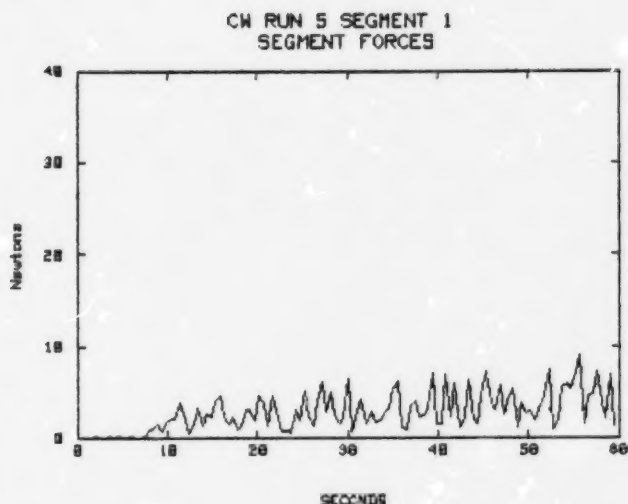


S1 RUN 2 SEGMENT 3
X POSITION



S1 RUN 2 SEGMENT 3
Z POSITION





STATISTICS FOR INTERVAL FROM 25.00 TO 60.00 Seconds

SAMPLES CALCULATED EVERY .488 SECS

TEST CW RUN 5 DATE:

SEGMENT 1

AVERAGE NORMAL FORCE 4.466 STANDARD DEVIATION 1.729

AVERAGE X POSITION 2.220 STANDARD DEVIATION .076

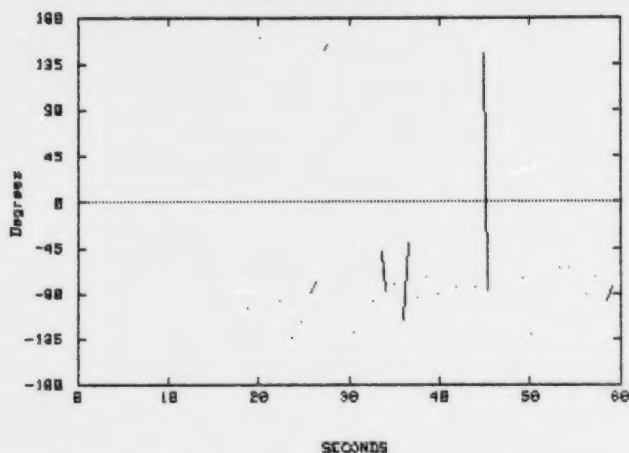
AVERAGE Z POSITION .043 STANDARD DEVIATION .007

AVERAGE FRICTION COEFF .392 STANDARD DEVIATION .227

PROJECTED FRICT. DIR. -51.170 STANDARD DEVIATION 110.664

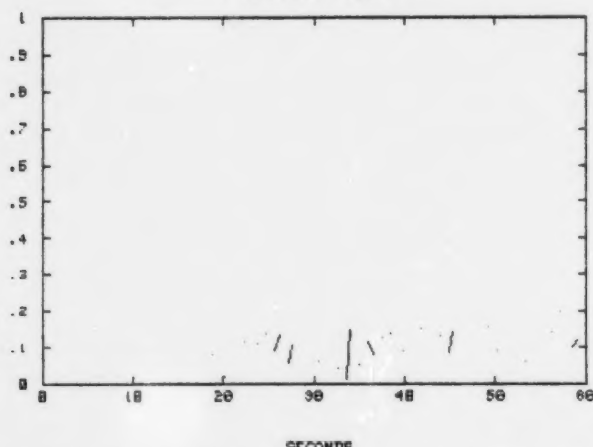
NUMBER OF DATA POINTS USED IN STATISTICS: 17

CW RUN 5 SEGMENT 2
FRICTION DIRECTION



.516393442623 0
.516393442623 0

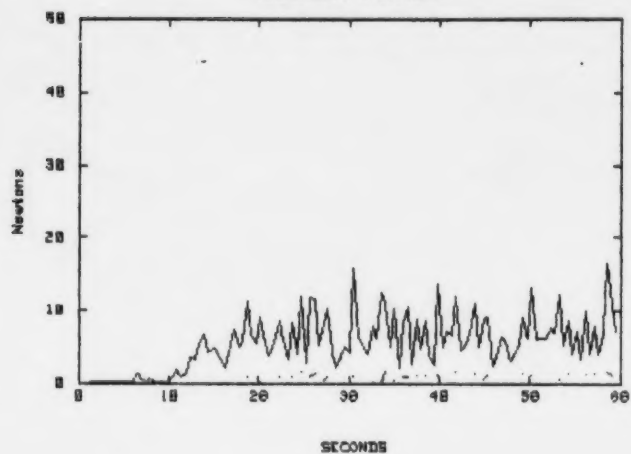
CW RUN 5 SEGMENT 2
FRICTION COEFF



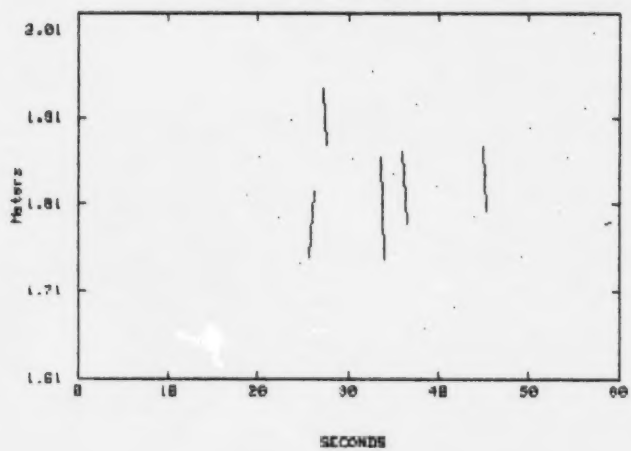
STATISTICS FOR INTERVAL FROM .52 TO 59.53 Seconds
SAMPLES CALCULATED EVERY .488 SECS
TEST CW RUN 5 DATE:
SEGMENT 2

AVERAGE NORMAL FORCE	6.765	STANDARD DEVIATION	3.118
AVERAGE X POSITION	1.835	STANDARD DEVIATION	.077
AVERAGE Z POSITION	.053	STANDARD DEVIATION	.005
AVERAGE FRICTION COEFF	.106	STANDARD DEVIATION	.042
PROJECTED FRICT. DIR.	-57.952	STANDARD DEVIATION	83.597
NUMBER OF DATA POINTS USED IN STATISTICS:		31	

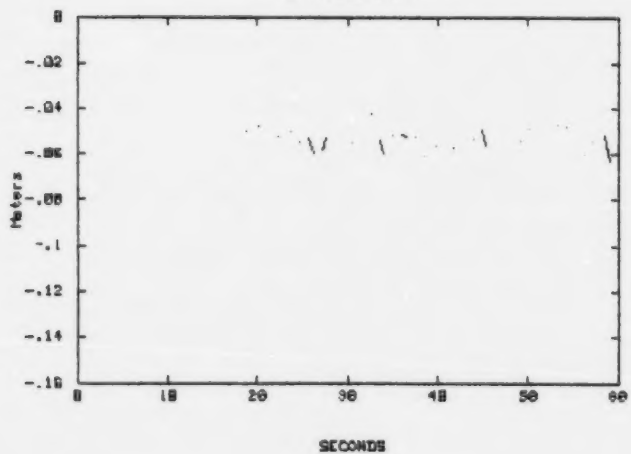
CW RUN 5 SEGMENT 2
SEGMENT FORCES

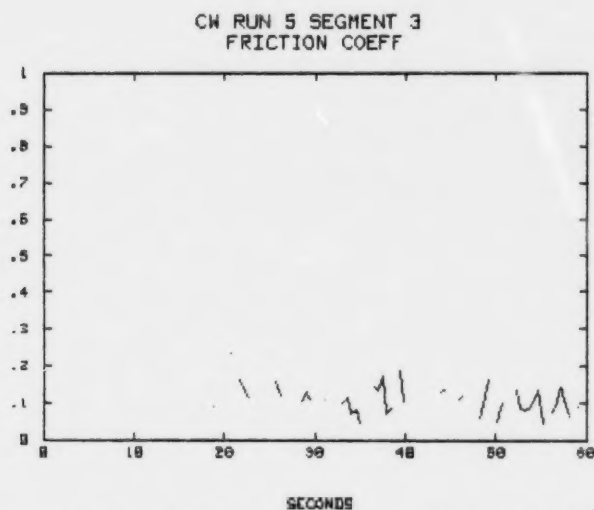
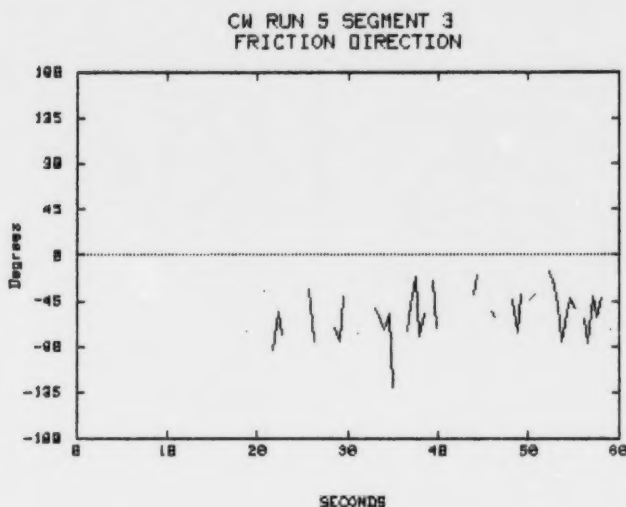


CW RUN 5 SEGMENT 2
X POSITION



CW RUN 5 SEGMENT 2
Z POSITION

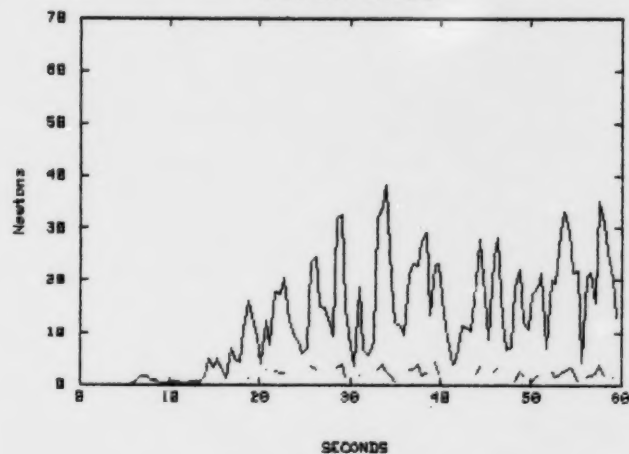




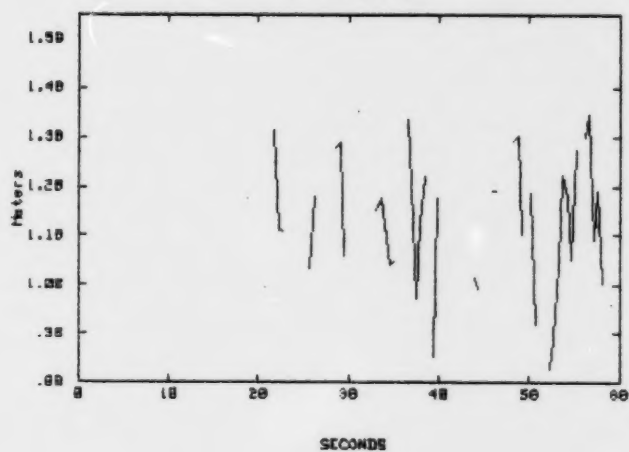
STATISTICS FOR INTERVAL FROM .52 TO 59.53 Seconds
 SAMPLES CALCULATED EVERY .488 SECS
 TEST CW RUN 5 DATE:
 SEGMENT 3

AVERAGE NORMAL FORCE	16.145	STANDARD DEVIATION	8.871
AVERAGE X POSITION	1.211	STANDARD DEVIATION	.134
AVERAGE Z POSITION	.051	STANDARD DEVIATION	.013
AVERAGE FRICTION COEFF	.113	STANDARD DEVIATION	.037
PROJECTED FRICT. DIR.	-57.693	STANDARD DEVIATION	22.712
NUMBER OF DATA POINTS USED IN STATISTICS:		45	

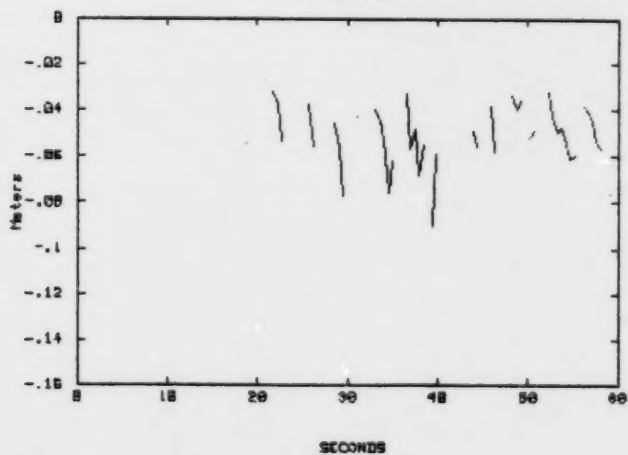
CW RUN 5 SEGMENT 3
SEGMENT FORCES

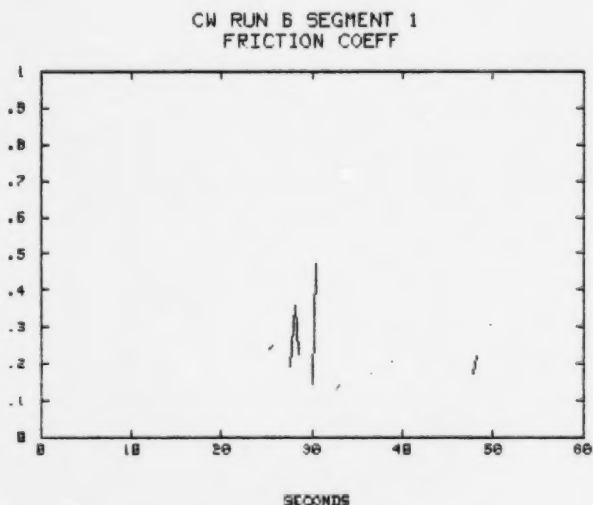
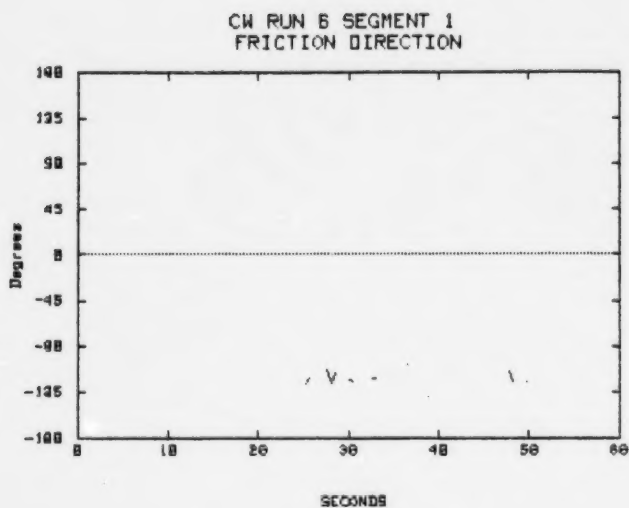


CW RUN 5 SEGMENT 3
X POSITION



CW RUN 5 SEGMENT 3
Z POSITION



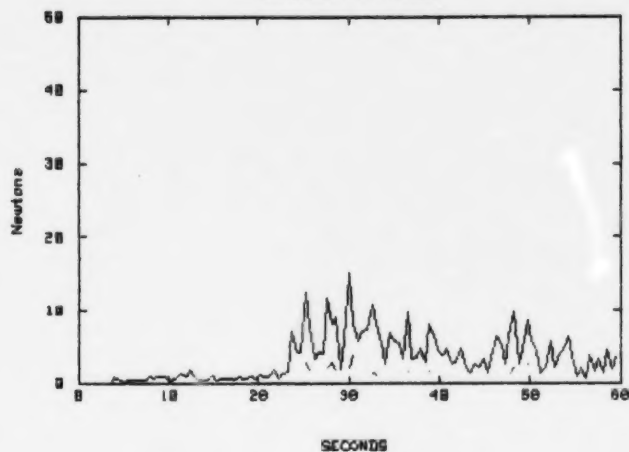


STATISTICS FOR INTERVAL FROM 25.00 TO 54.00 Seconds
 SAMPLES CALCULATED EVERY .496 SECS

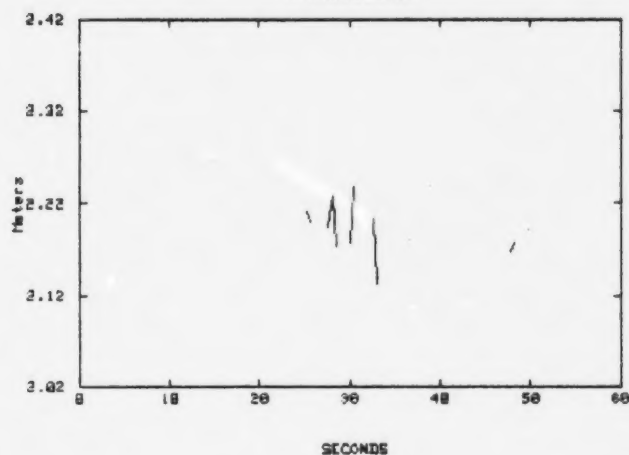
TEST CW RUN 6 DATE:
 SEGMENT 1

AVERAGE NORMAL FORCE	6.800	STANDARD DEVIATION	2.737
AVERAGE X POSITION	2.202	STANDARD DEVIATION	.032
AVERAGE Z POSITION	.039	STANDARD DEVIATION	.004
AVERAGE FRICTION COEFF	.267	STANDARD DEVIATION	.146
PROJECTED FRICT. DIR.	-123.750	STANDARD DEVIATION	7.941
NUMBER OF DATA POINTS USED IN STATISTICS:		42	

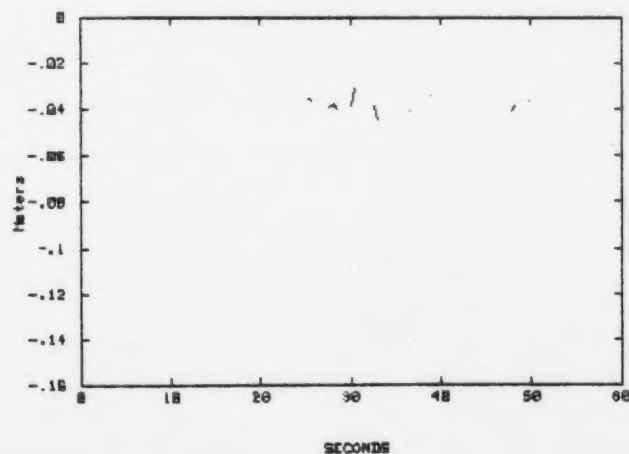
CW RUN 6 SEGMENT 1
SEGMENT FORCES



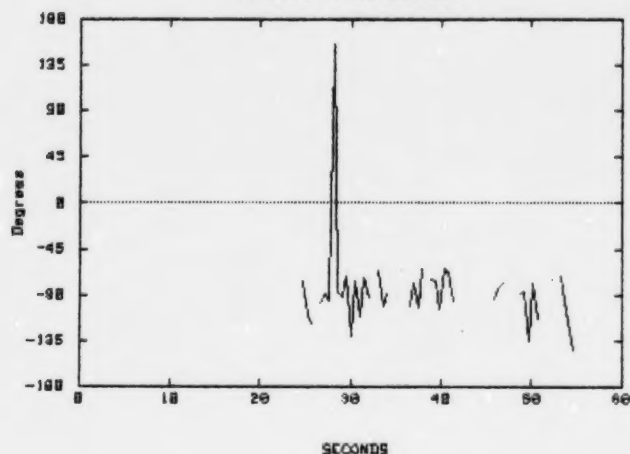
CW RUN 6 SEGMENT 1
X POSITION



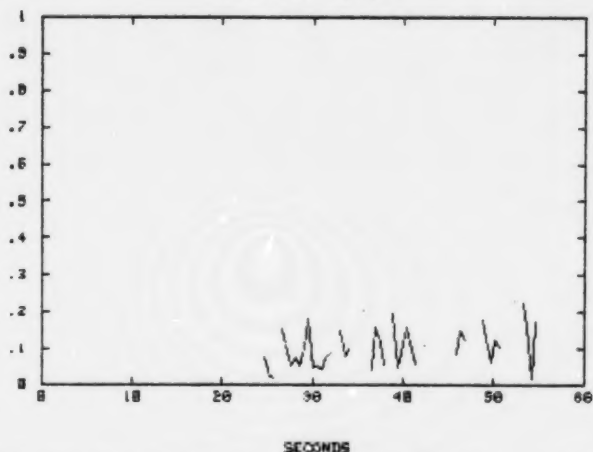
CW RUN 6 SEGMENT 1
Z POSITION



CW RUN 6 SEGMENT 2
FRICTION DIRECTION



CW RUN 6 SEGMENT 2
FRICTION COEFF



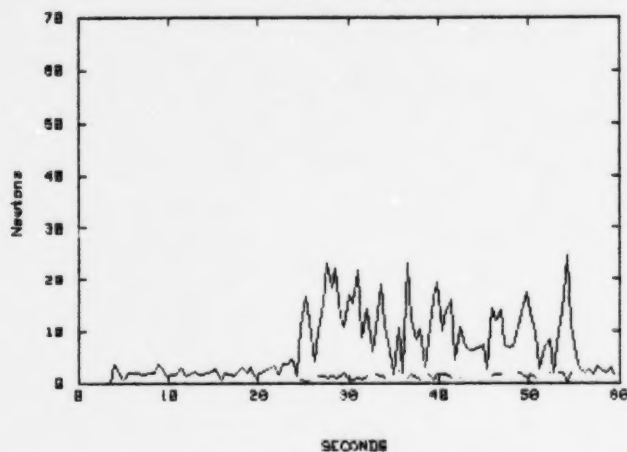
STATISTICS FOR INTERVAL FROM 25.00 TO 54.00 Seconds
SAMPLES CALCULATED EVERY .488 SECS

TEST CW RUN 6 DATE:
SEGMENT 2

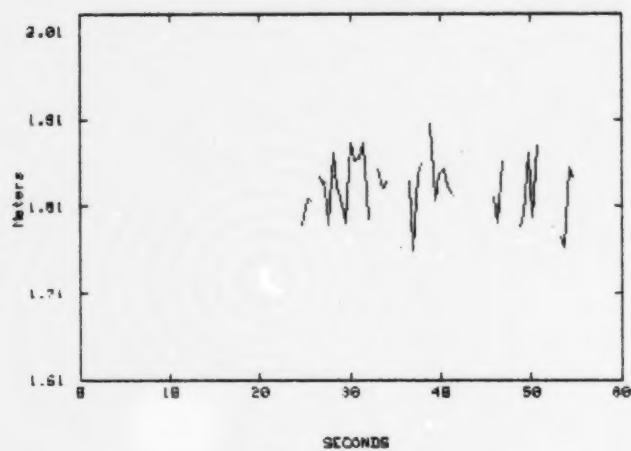
AVERAGE NORMAL FORCE	11.248	STANDARD DEVIATION	5.368
AVERAGE X POSITION	1.829	STANDARD DEVIATION	.037
AVERAGE Z POSITION	.055	STANDARD DEVIATION	.004
AVERAGE FRICTION COEFF	.109	STANDARD DEVIATION	.055
PROJECTED FRICT. DIR.	-83.945	STANDARD DEVIATION	42.419

NUMBER OF DATA POINTS USED IN STATISTICS: 40

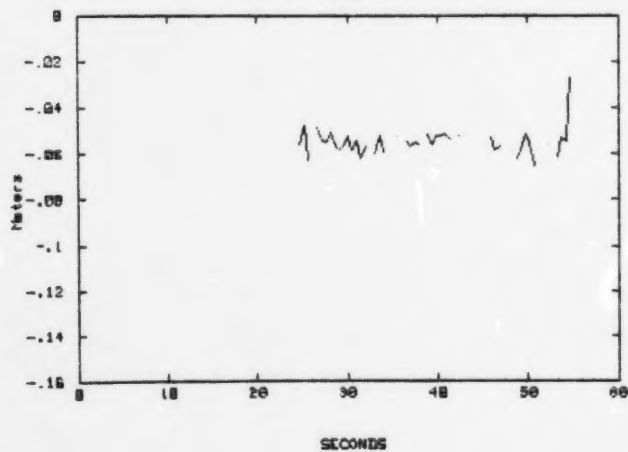
CW RUN 6 SEGMENT 2
SEGMENT FORCES

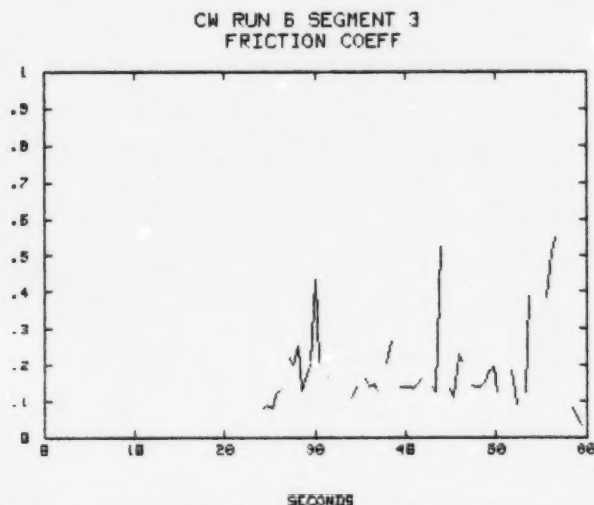
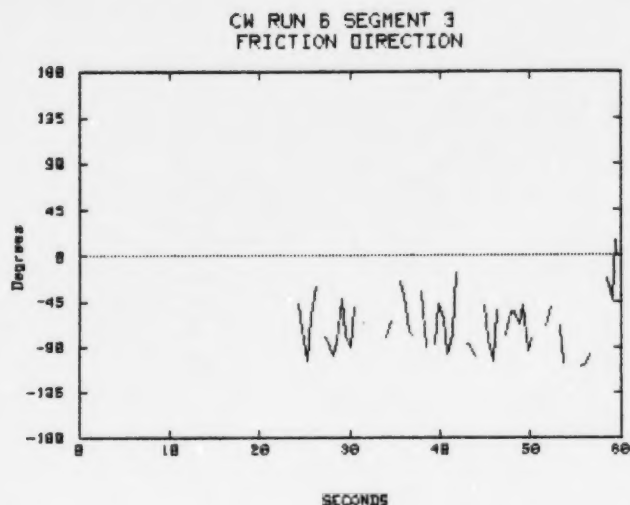


CW RUN 6 SEGMENT 2
X POSITION



CW RUN 6 SEGMENT 2
Z POSITION



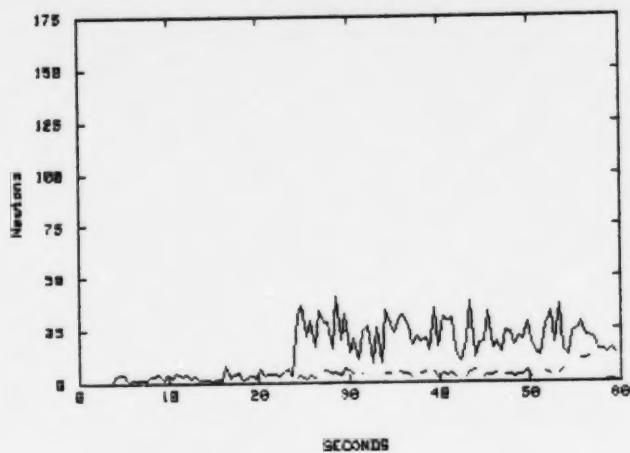


STATISTICS FOR INTERVAL FROM 25.00 TO 54.00 Seconds
 SAMPLES CALCULATED EVERY .488 SECS

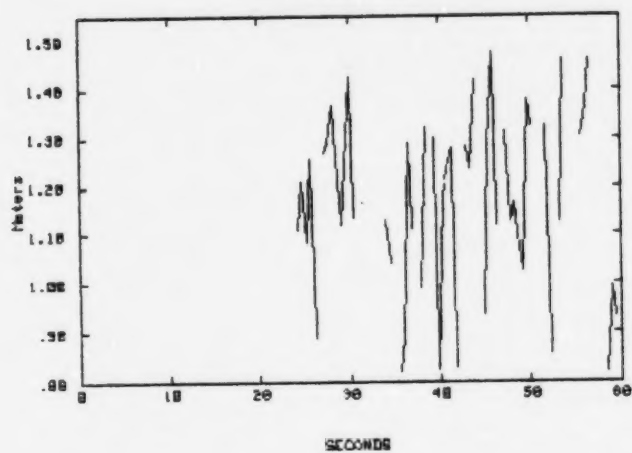
TEST CW RUN 6 DATE:
 SEGMENT 3

AVERAGE NORMAL FORCE	22.962	STANDARD DEVIATION	7.909
AVERAGE X POSITION	1.254	STANDARD DEVIATION	.175
AVERAGE Z POSITION	.043	STANDARD DEVIATION	.011
AVERAGE FRICTION COEFF	.178	STANDARD DEVIATION	.085
PROJECTED FRICT. DIR.	-69.954	STANDARD DEVIATION	22.244
NUMBER OF DATA POINTS USED IN STATISTICS:		44	

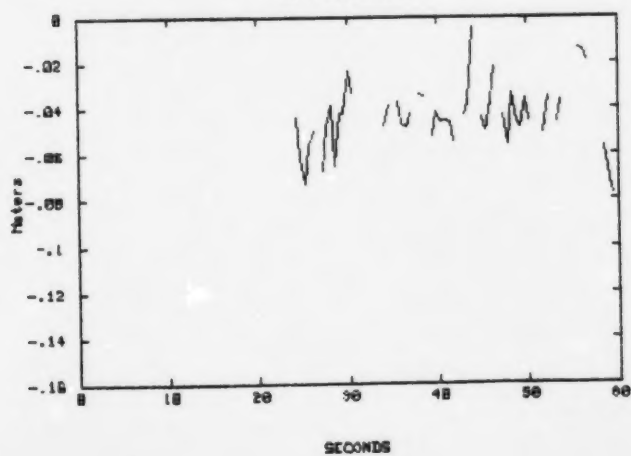
CW RUN 6 SEGMENT 3
SEGMENT FORCES



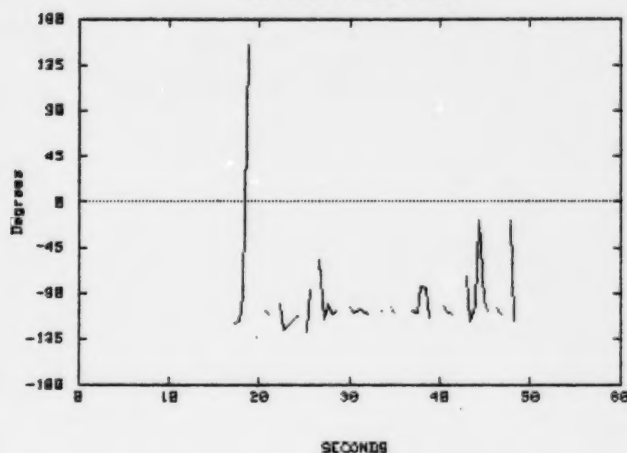
CW RUN 6 SEGMENT 3
X POSITION



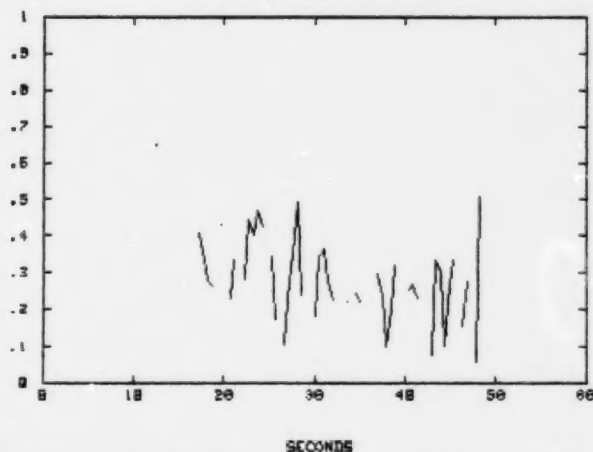
CW RUN 6 SEGMENT 3
Z POSITION



CW RUN 7 SEGMENT 1
FRICTION DIRECTION



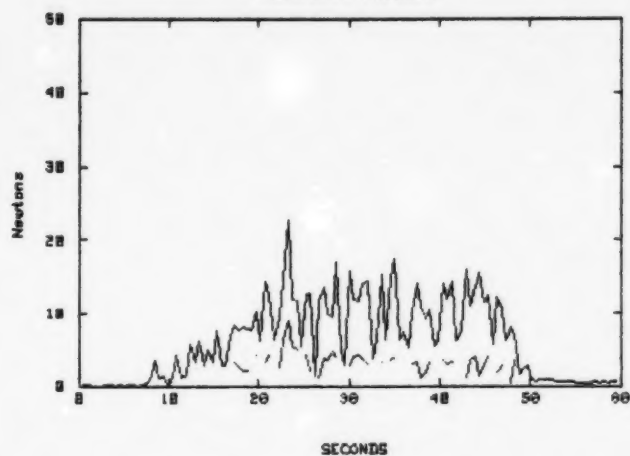
CW RUN 7 SEGMENT 1
FRICTION COEFF



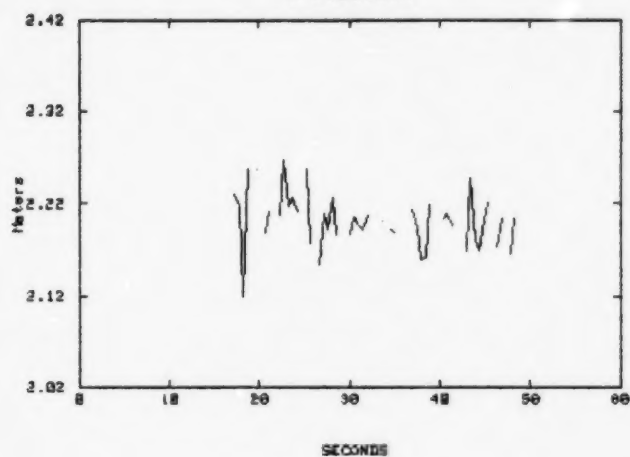
STATISTICS FOR INTERVAL FROM .52 TO 59.53 Seconds
 SAMPLES CALCULATED EVERY .488 SECS
 TEST CW RUN 7 DATE:
 SEGMENT 1

AVERAGE NORMAL FORCE	9.417	STANDARD DEVIATION	4.342
AVERAGE X POSITION	2.202	STANDARD DEVIATION	.029
AVERAGE Z POSITION	.038	STANDARD DEVIATION	.004
AVERAGE FRICTION COEFF	.282	STANDARD DEVIATION	.107
PROJECTED FRICT. DIR.	-96.911	STANDARD DEVIATION	44.326
NUMBER OF DATA POINTS USED IN STATISTICS:		45	

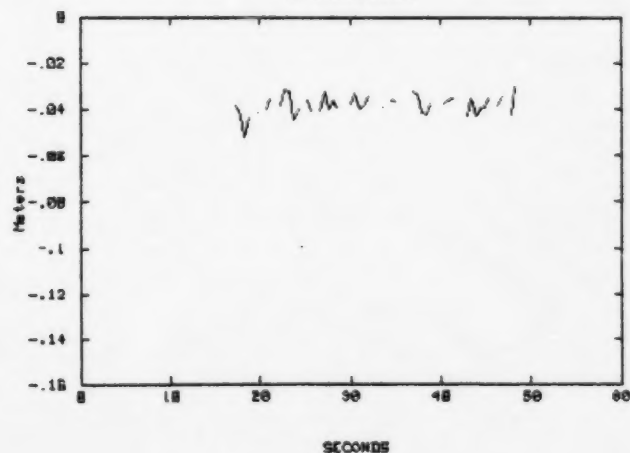
CW RUN 7 SEGMENT 1
SEGMENT FORCES

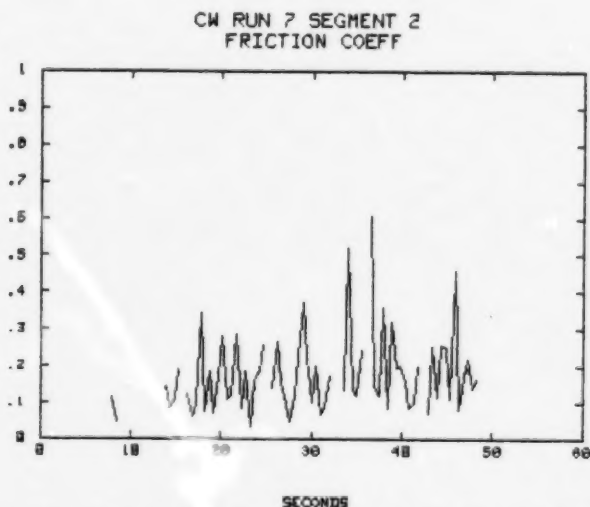
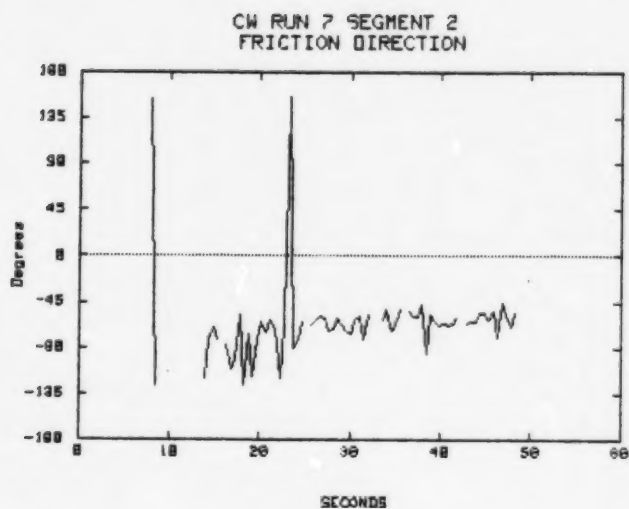


CW RUN 7 SEGMENT 1
X POSITION



CW RUN 7 SEGMENT 1
Z POSITION



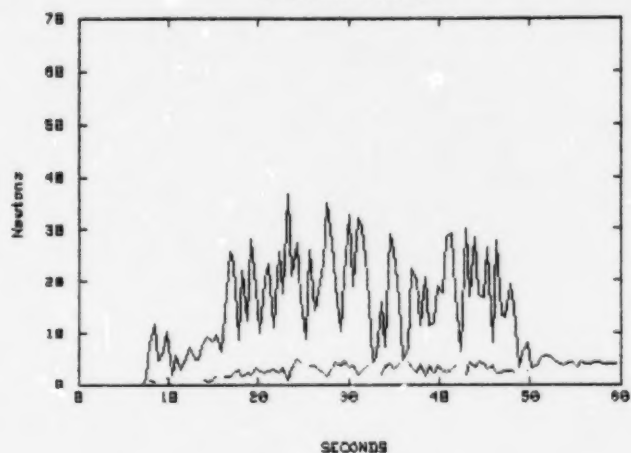


STATISTICS FOR INTERVAL FROM 20.00 TO 45.00 Seconds
 SAMPLES CALCULATED EVERY .488 SECS

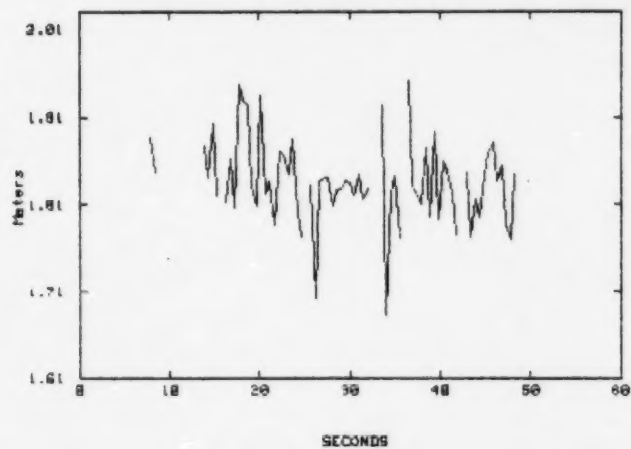
TEST CW RUN 7 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	19.492	STANDARD DEVIATION	8.307
AVERAGE X POSITION	1.829	STANDARD DEVIATION	.049
AVERAGE Z POSITION	.057	STANDARD DEVIATION	.005
AVERAGE FRICTION COEFF	.189	STANDARD DEVIATION	.114
PROJECTED FRICT. DIR.	-62.147	STANDARD DEVIATION	34.713
NUMBER OF DATA POINTS USED IN STATISTICS:		46	

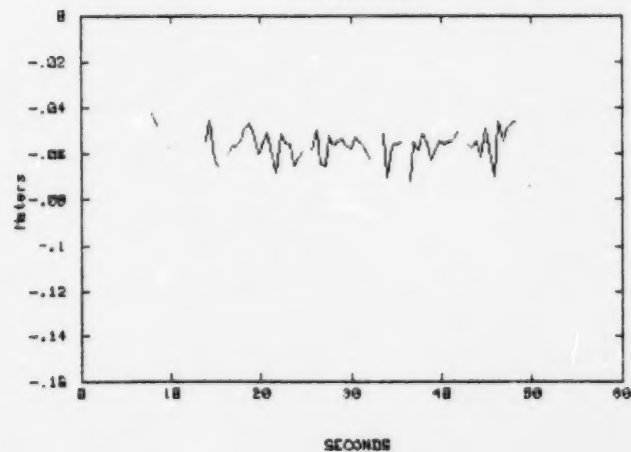
CW RUN 7 SEGMENT 2
SEGMENT FORCES



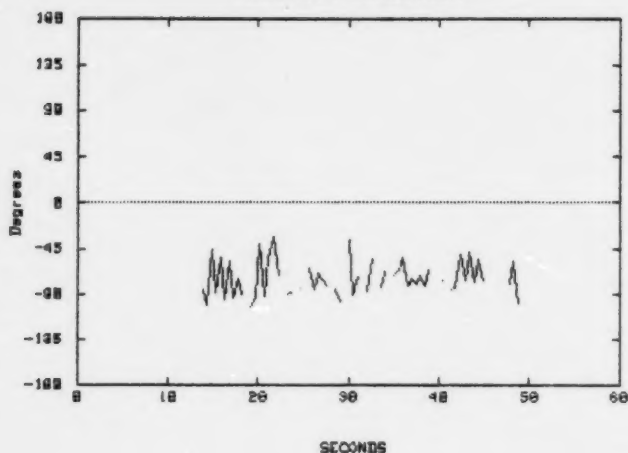
CW RUN 7 SEGMENT 2
X POSITION



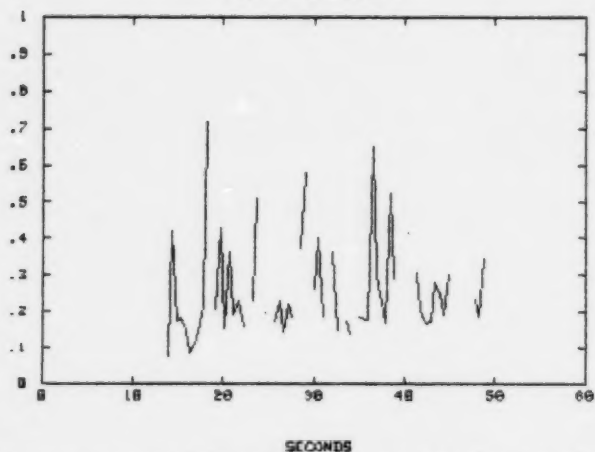
CW RUN 7 SEGMENT 2
Z POSITION



CW RUN 7 SEGMENT 3
FRICTION DIRECTION



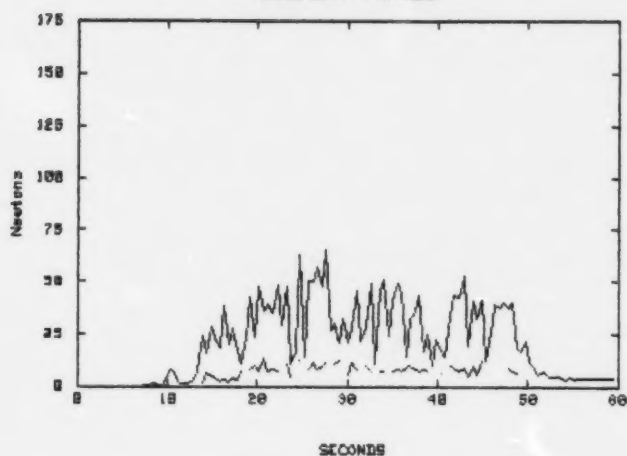
CW RUN 7 SEGMENT 3
FRICTION COEFF



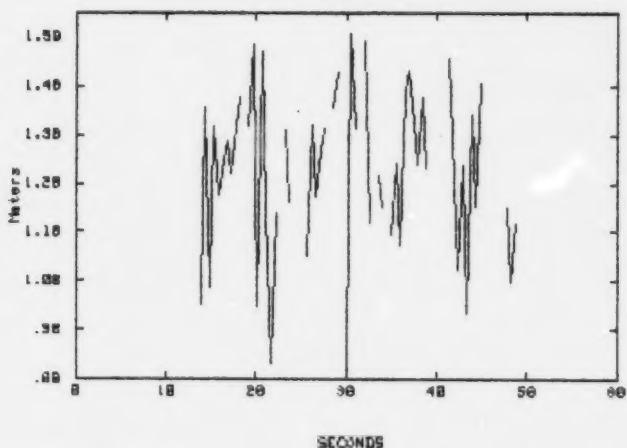
STATISTICS FOR INTERVAL FROM 20.00 TO 45.00 Seconds
 SAMPLES CALCULATED EVERY .488 SECS
 TEST CW RUN 7 DATE:
 SEGMENT 3

AVERAGE NORMAL FORCE	34.844	STANDARD DEVIATION	14.334
AVERAGE X POSITION	1.316	STANDARD DEVIATION	.170
AVERAGE Z POSITION	.035	STANDARD DEVIATION	.012
AVERAGE FRICTION COEFF	.266	STANDARD DEVIATION	.125
PROJECTED FRICT. DIR.	-72.101	STANDARD DEVIATION	15.519
NUMBER OF DATA POINTS USED IN STATISTICS:		40	

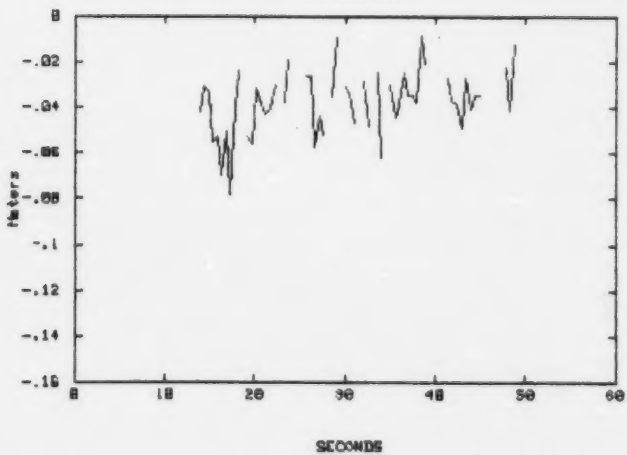
CW RUN 7 SEGMENT 3
SEGMENT FORCES



CW RUN 7 SEGMENT 3
X POSITION



CW RUN 7 SEGMENT 3
Z POSITION





J.3 ICE SHEET #3 TEST RUNS

This appendix contains the results of the tests conducted in ice sheet #3. The results are presented in graph form against time. Five graphs for each segment in each test are presented. In order they are: friction direction of the force; friction coefficient; segment forces, which is the normal force and friction force superimposed on one graph; x position of the force; and z position of the force. The definition of the friction direction is given in Section 3, Volume I. The data for the graphs was calculated from the transducer measurement using the data reduction algorithm outlined in Section 3, Volume I. Each data point on the graph was derived from the average of two consecutive transducer measurements. The data points are approximately 0.5 seconds apart. Discontinuities in the graphs (as discussed in Section 7, Volume I) occur when the forces are too low to be accurately traced by the segments. In cases where less than 20 points were resolved by the algorithm only the segment forces plot has been given. In Table J.3 the particulars of each test are given. The graphs for each test follow in the order in which they are given in the Table. For each test the segments are given in order 1 to 3. Included in each group of five graphs the statistics of the graphed variables are given over the active time period of the test.

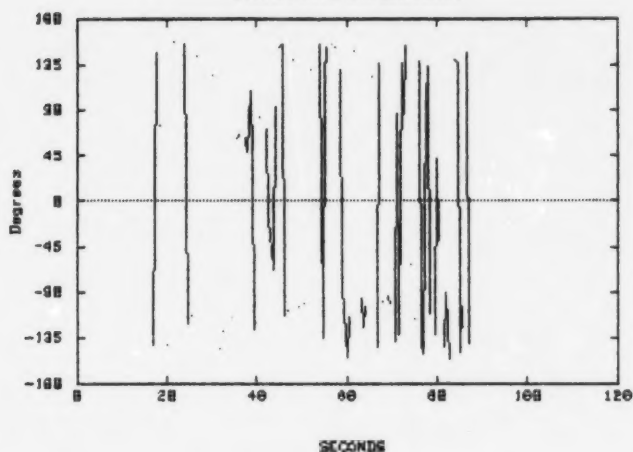
TABLE J.3

ICE TESTS CONDUCTED DURING ICE SHEET #3

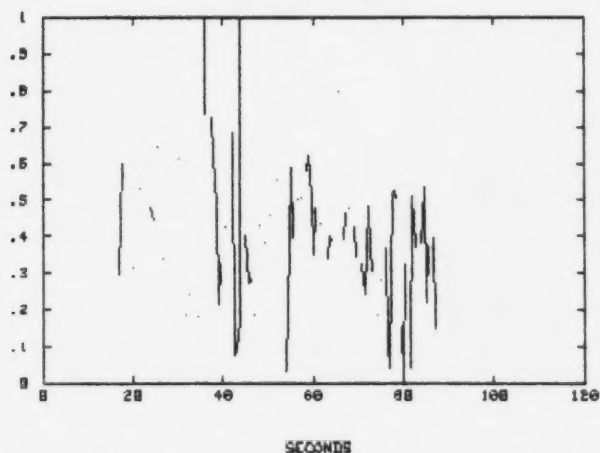
ICE SHEET	RUN	TYPE OF TEST	ICE THICKNESS mm	ICE STRENGTH kPa	MODEL SPEED m/s	FULL SCALE SPEED knots	LENGTH OF TEST RUN L/L_{VL}
3	S31	NS	47	30	0.15	1.3	2.07
3	S32	NS	47	30	0.30	2.6	2.16
3	CW8	CW	49	30	0.10	0.9	1.75
3	CW9	CW	49	30	0.22	1.9	2.84

Note: $L_{VL} = 4.575$ m

S3 RUN 11 SEGMENT 1
FRICTION DIRECTION



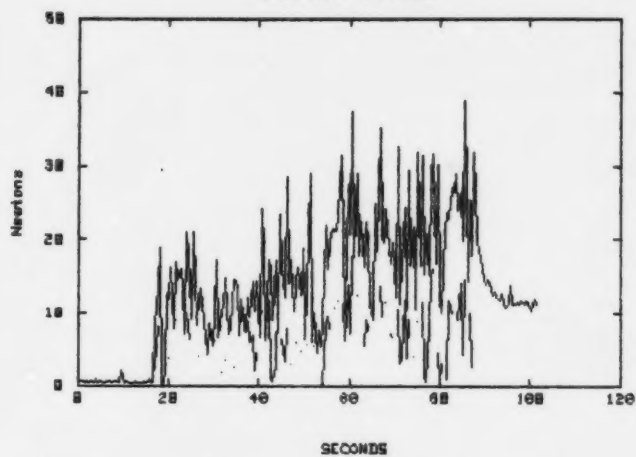
S3 RUN 11 SEGMENT 1
FRICTION COEFF



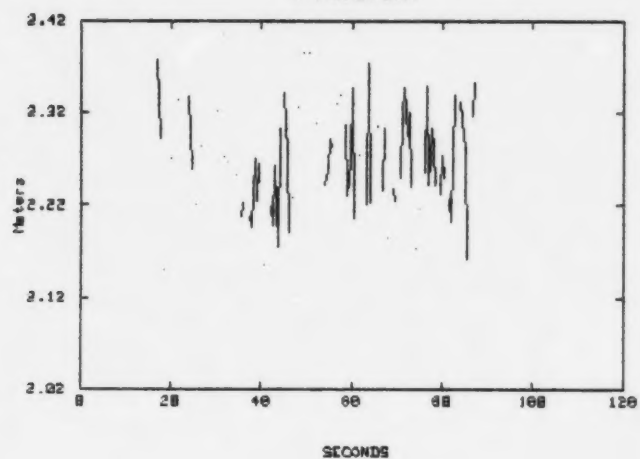
STATISTICS FOR INTERVAL FROM .52 TO 101.52 Seconds
 SAMPLES CALCULATED EVERY .498 SECS
 TEST S3 RUN 11 DATE:
 SEGMENT 1

AVERAGE NORMAL FORCE	16.053	STANDARD DEVIATION	7.346
AVERAGE X POSITION	2.269	STANDARD DEVIATION	.056
AVERAGE Z POSITION	.051	STANDARD DEVIATION	.010
AVERAGE FRICTION COEFF	.479	STANDARD DEVIATION	.644
PROJECTED FRICT. DIR.	-2.014	STANDARD DEVIATION	120.570
NUMBER OF DATA POINTS USED IN STATISTICS:		81	

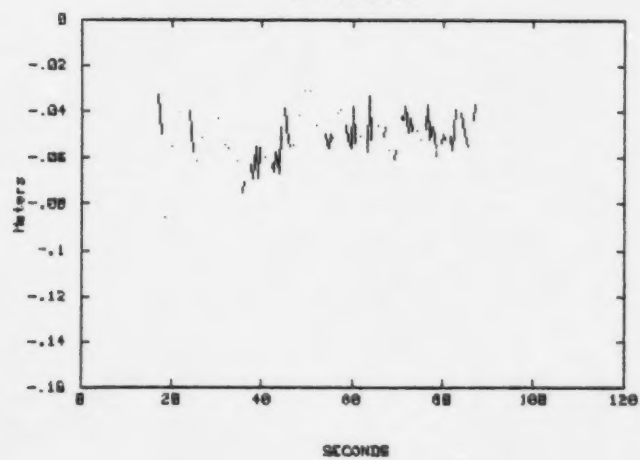
S3 RUN 11 SEGMENT 1
SEGMENT FORCES



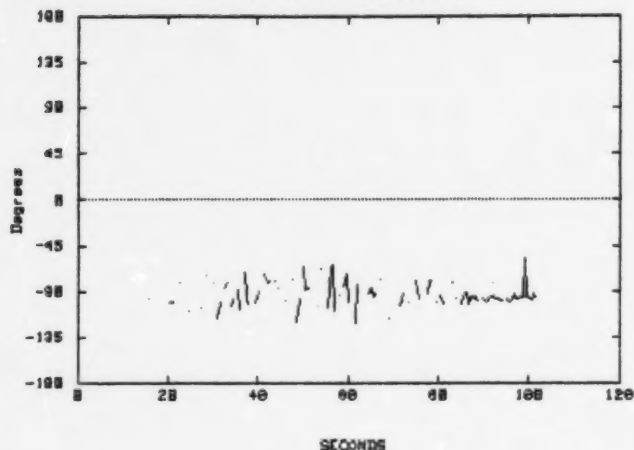
S3 RUN 11 SEGMENT 1
X POSITION



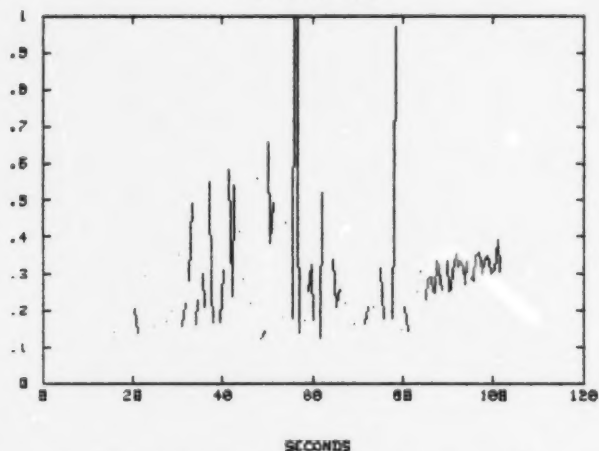
S3 RUN 11 SEGMENT 1
Z POSITION



S3 RUN 12 SEGMENT 2
FRICTION DIRECTION



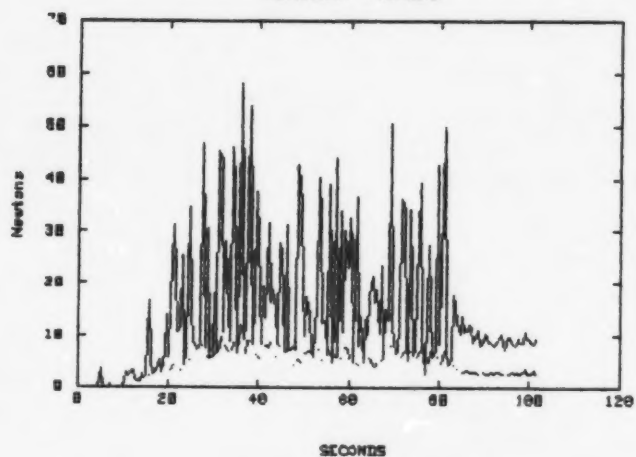
S3 RUN 12 SEGMENT 2
FRICTION COEFF



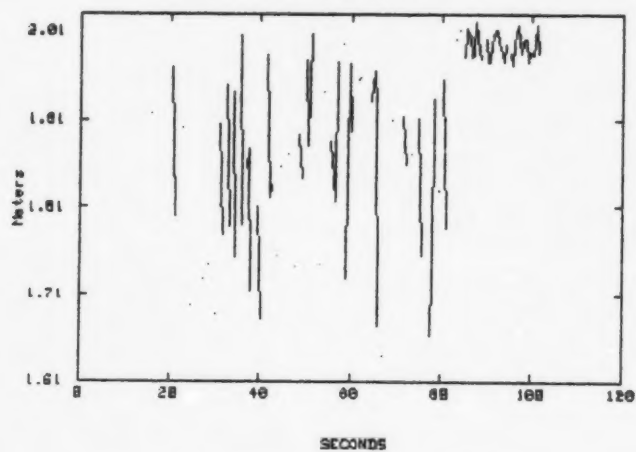
STATISTICS FOR INTERVAL FROM .52 TO 101.52 Seconds
 SAMPLES CALCULATED EVERY .498 SECS
 TEST S3 RUN 12 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	15.636	STANDARD DEVIATION	12.341
AVERAGE X POSITION	1.902	STANDARD DEVIATION	.105
AVERAGE Z POSITION	.057	STANDARD DEVIATION	.020
AVERAGE FRICTION COEFF	.304	STANDARD DEVIATION	.163
PROJECTED FRICT. DIR.	-92.982	STANDARD DEVIATION	11.787
NUMBER OF DATA POINTS USED IN STATISTICS:		96	

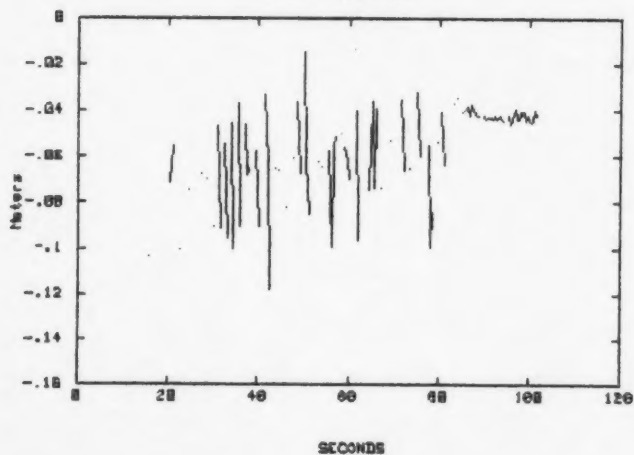
S3 RUN 12 SEGMENT 2
SEGMENT FORCES



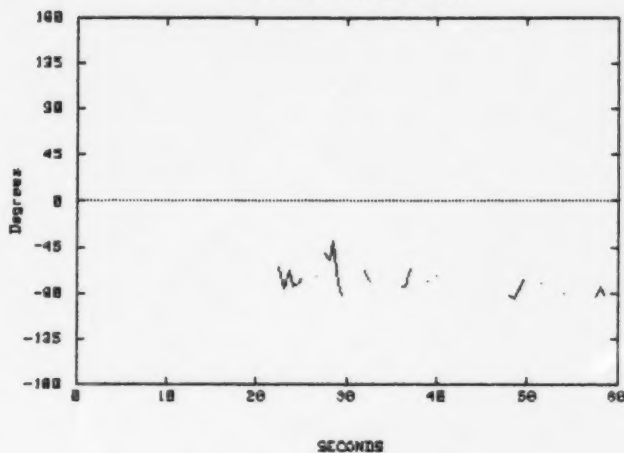
S3 RUN 12 SEGMENT 2
X POSITION



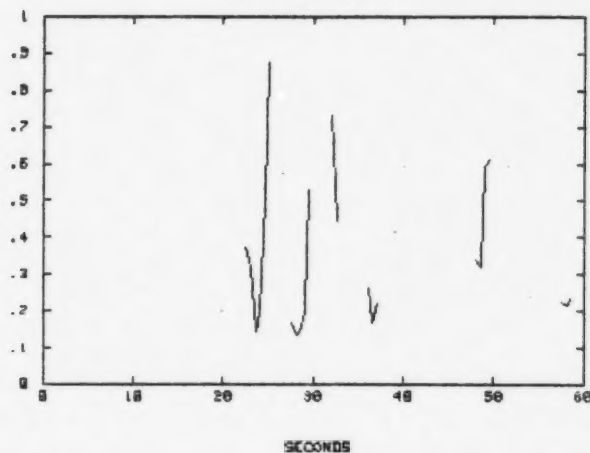
S3 RUN 12 SEGMENT 2
Z POSITION



S3 RUN 13 SEGMENT 3
FRICTION DIRECTION



S3 RUN 13 SEGMENT 3
FRICTION COEFF

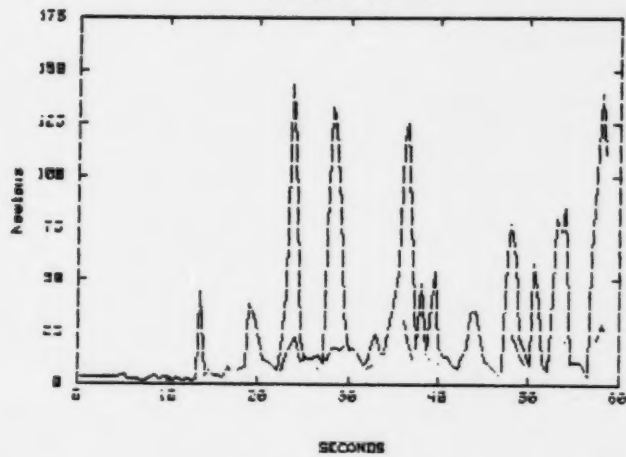


STATISTICS FOR INTERVAL FROM .52 TO 58.52 Seconds
SAMPLES CALCULATED EVERY .496 SECS
TEST S3 RUN 13 DATE:
SEGMENT 3

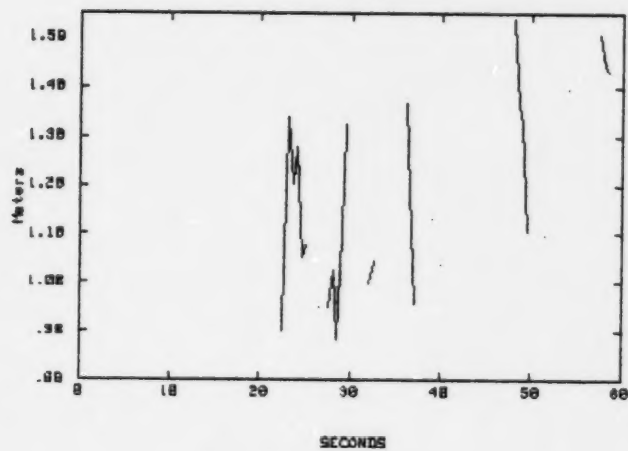
AVERAGE NORMAL FORCE	28.473	STANDARD DEVIATION	34.661
AVERAGE X POSITION	1.259	STANDARD DEVIATION	.191
AVERAGE Z POSITION	.060	STANDARD DEVIATION	.030
AVERAGE FRICTION COEFF	.371	STANDARD DEVIATION	.199
PROJECTED FRICT. DIR.	-77.315	STANDARD DEVIATION	13.125

NUMBER OF DATA POINTS USED IN STATISTICS 28.

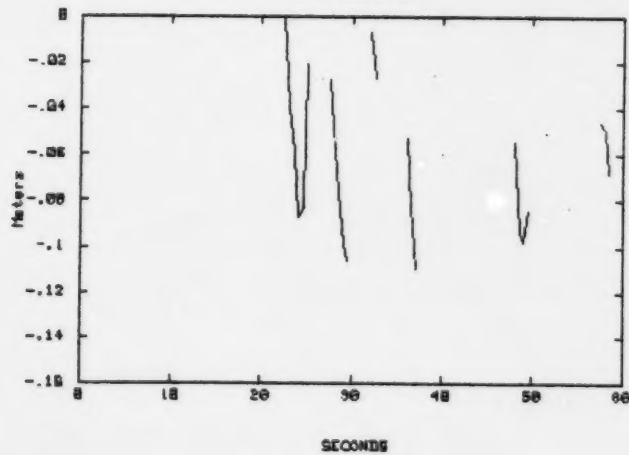
S3 RUN 13 SEGMENT 3
SEGMENT FORCES



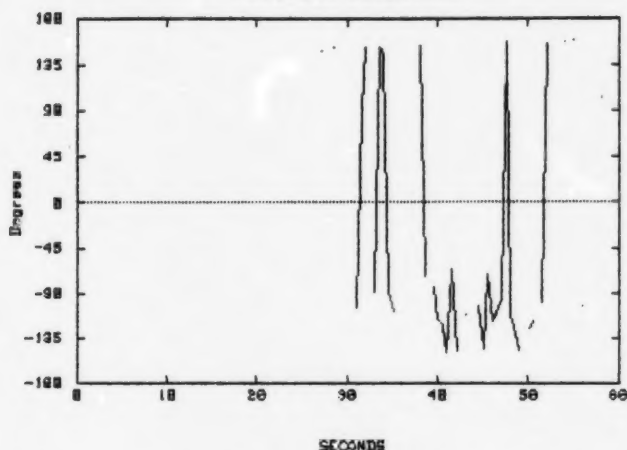
S3 RUN 13 SEGMENT 3
X POSITION



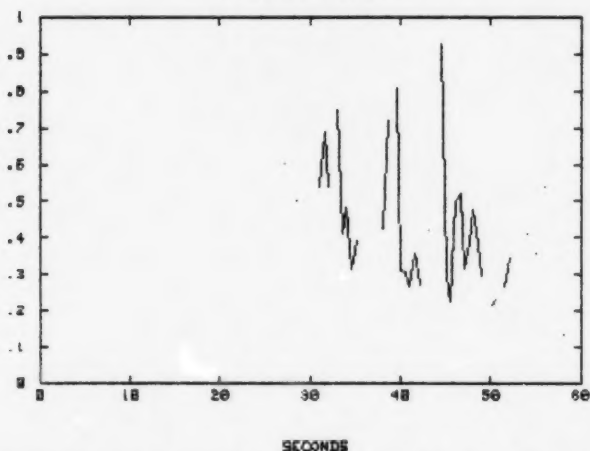
S3 RUN 13 SEGMENT 3
Z POSITION



S3 RUN 2 SEGMENT 1
FRICTION DIRECTION



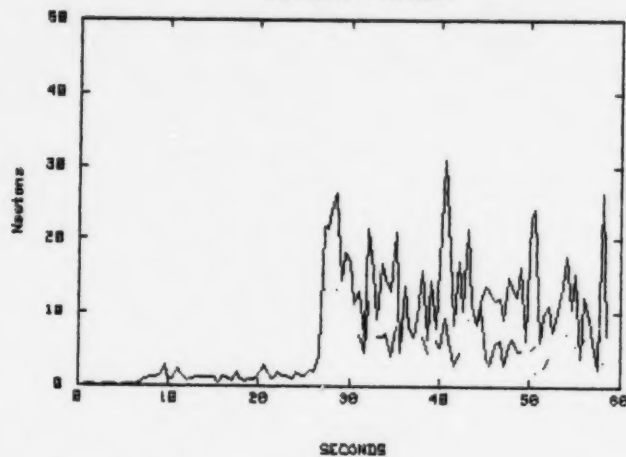
S3 RUN 2 SEGMENT 1
FRICTION COEFF



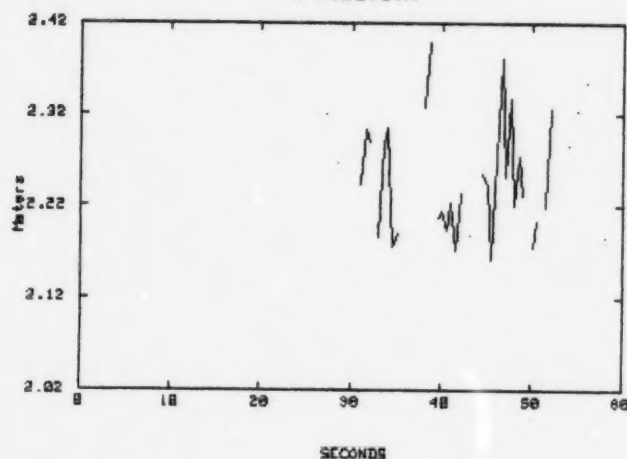
STATISTICS FOR INTERVAL FROM 25.00 TO 58.00 Seconds
 SAMPLES CALCULATED EVERY .496 SECS
 TEST S3 RUN 2 DATE:
 SEGMENT 1

AVERAGE NORMAL FORCE	13.196	STANDARD DEVIATION	6.151
AVERAGE X POSITION	2.257	STANDARD DEVIATION	.062
AVERAGE Z POSITION	.047	STANDARD DEVIATION	.008
AVERAGE FRICTION COEFF	.439	STANDARD DEVIATION	.171
PROJECTED FRICT. DIR.	-30.626	STANDARD DEVIATION	120.208
NUMBER OF DATA POINTS USED IN STATISTICS:		36	

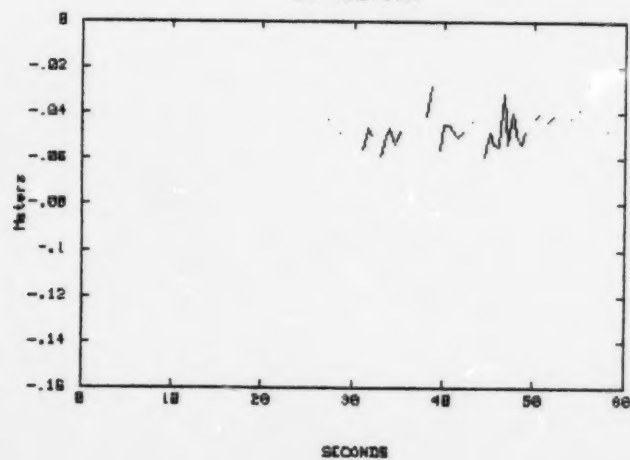
S3 RUN 2 SEGMENT 1
SEGMENT FORCES

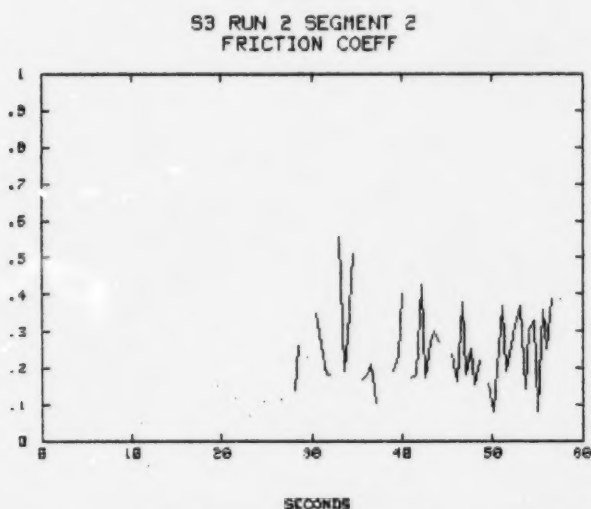
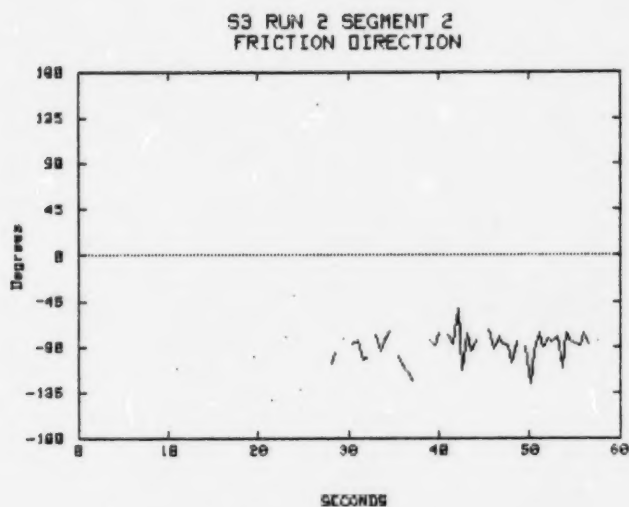


S3 RUN 2 SEGMENT 1
X POSITION



S3 RUN 2 SEGMENT 1
Z POSITION





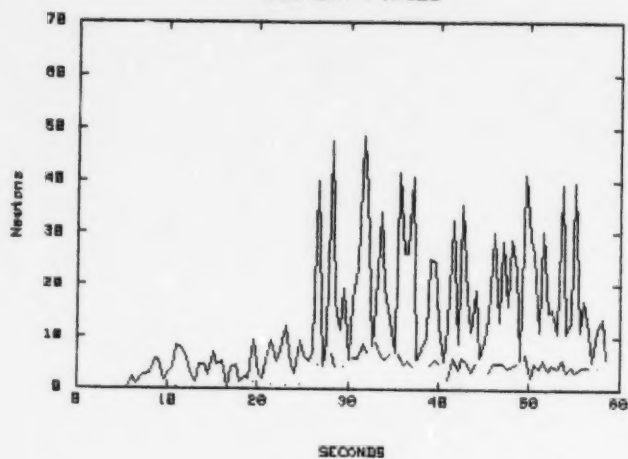
STATISTICS FOR INTERVAL FROM 25.00 TO 58.00 Seconds
 SAMPLES CALCULATED EVERY .496 SECS

TEST S3 RUN 2 DATE:
 SEGMENT 2

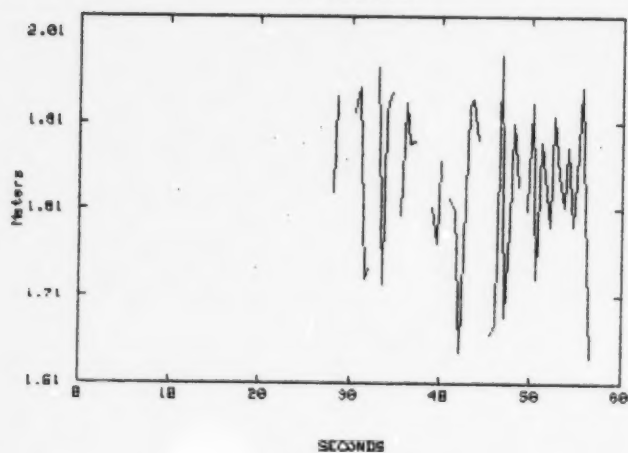
AVERAGE NORMAL FORCE	19.305	STANDARD DEVIATION	12.036
AVERAGE X POSITION	1.840	STANDARD DEVIATION	.089
AVERAGE Z POSITION	.053	STANDARD DEVIATION	.017
AVERAGE FRICTION COEFF	.252	STANDARD DEVIATION	.105
PROJECTED FRICT. DIR.	-84.610	STANDARD DEVIATION	36.418

NUMBER OF DATA POINTS USED IN STATISTICS: 49

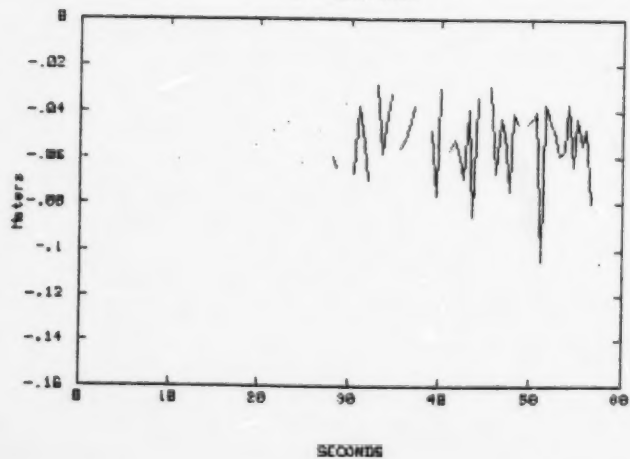
S3 RUN 2 SEGMENT 2
SEGMENT FORCES



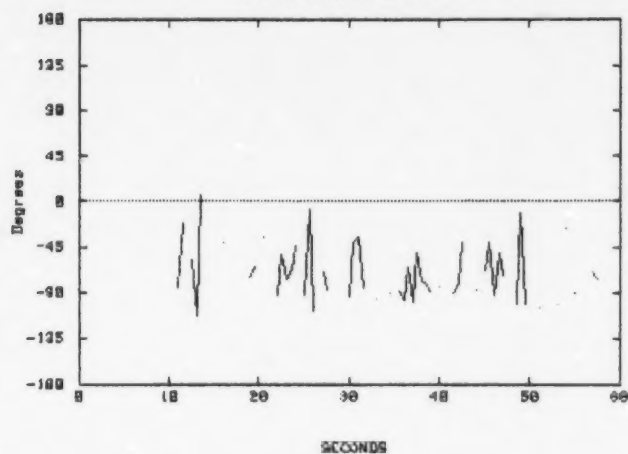
S3 RUN 2 SEGMENT 2
X POSITION



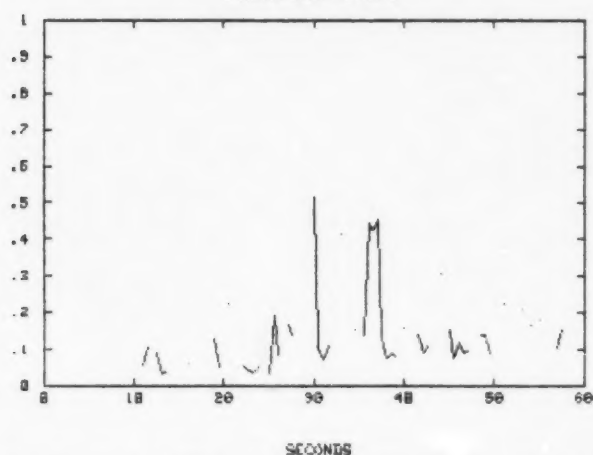
S3 RUN 2 SEGMENT 2
Z POSITION



S3 RUN 2 SEGMENT 3
FRICTION DIRECTION



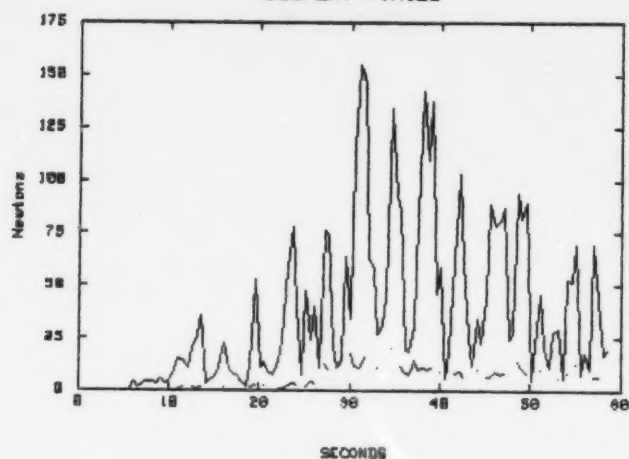
S3 RUN 2 SEGMENT 3
FRICTION COEFF



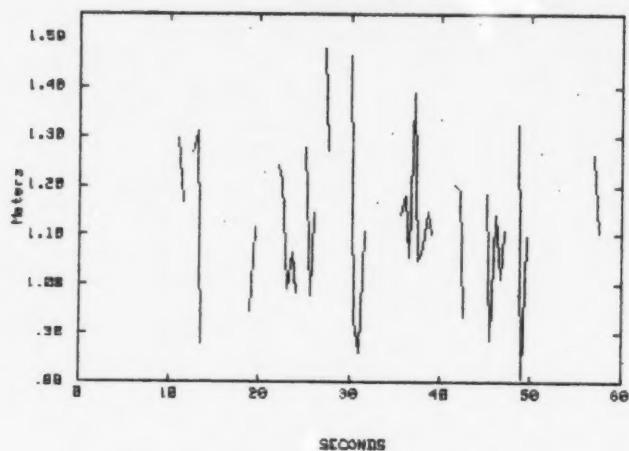
STATISTICS FOR INTERVAL FROM 25.00 TO 58.00 Seconds
 SAMPLES CALCULATED EVERY .496 SECS
 TEST S3 RUN 2 DATE:
 SEGMENT 3

AVERAGE NORMAL FORCE	53.821	STANDARD DEVIATION	38.609
AVERAGE X POSITION	1.237	STANDARD DEVIATION	.174
AVERAGE Z POSITION	.056	STANDARD DEVIATION	.021
AVERAGE FRICTION COEFF	.174	STANDARD DEVIATION	.119
PROJECTED FRICT. DIR.	-74.758	STANDARD DEVIATION	25.922
NUMBER OF DATA POINTS USED IN STATISTICS:		38	

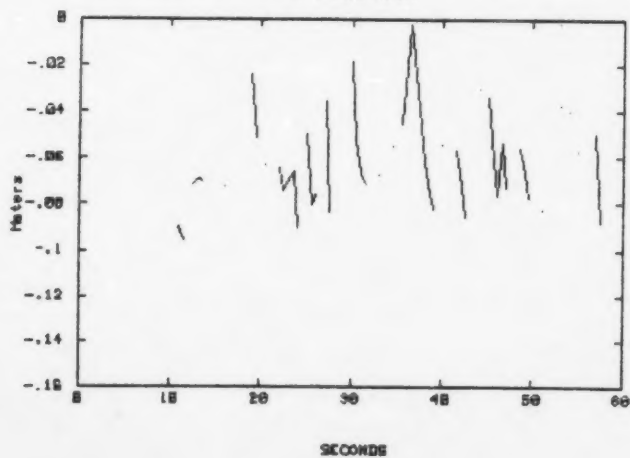
S3 RUN 2 SEGMENT 3
SEGMENT FORCES



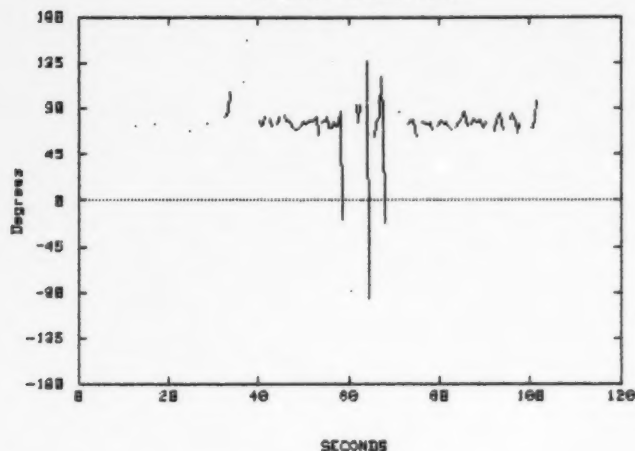
S3 RUN 2 SEGMENT 3
X POSITION



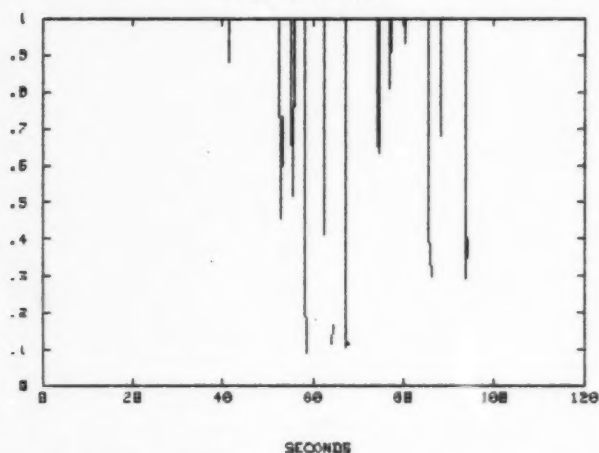
S3 RUN 2 SEGMENT 3
Z POSITION



CW RUN B SEGMENT 1
FRICTION DIRECTION



CW RUN B SEGMENT 1
FRICTION COEFF

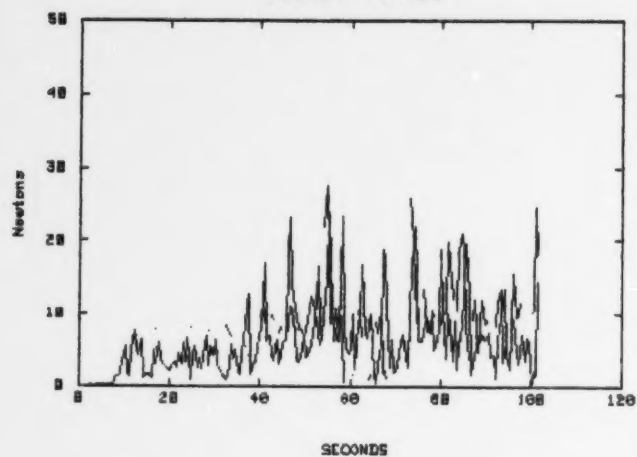


STATISTICS FOR INTERVAL FROM .52 TO 101.52 Seconds
SAMPLES CALCULATED EVERY .498 SECS
TEST CW RUN 8 DATE:
SEGMENT 1

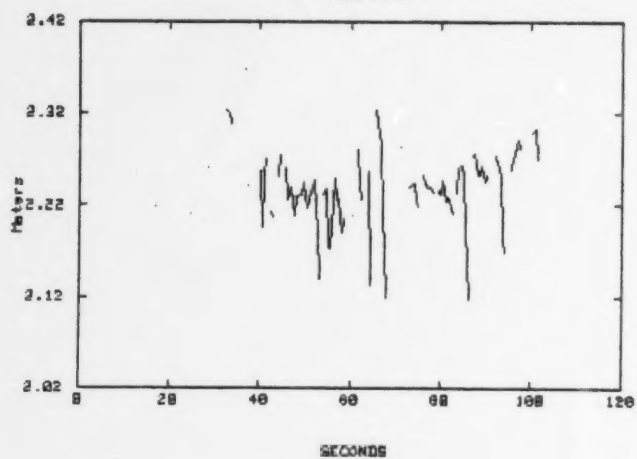
AVERAGE NORMAL FORCE	7.052	STANDARD DEVIATION	4.248
AVERAGE X POSITION	2.241	STANDARD DEVIATION	.042
AVERAGE Z POSITION	.062	STANDARD DEVIATION	.009
AVERAGE FRICTION COEFF	2.257	STANDARD DEVIATION	3.424
PROJECTED FRICT. DIR.	73.854	STANDARD DEVIATION	30.294

NUMBER OF DATA POINTS USED IN STATISTICS: 101

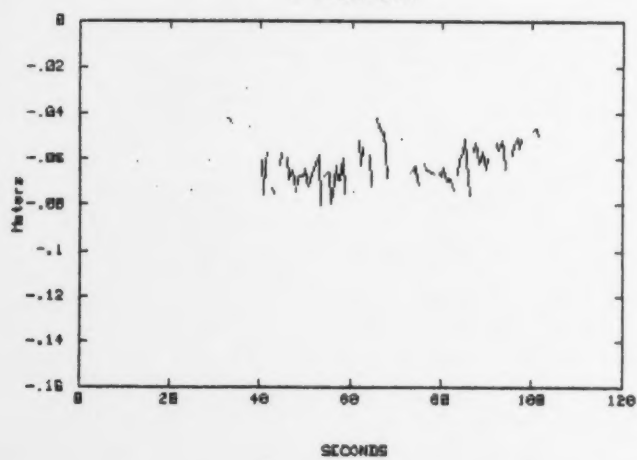
CW RUN B SEGMENT 1
SEGMENT FORCES



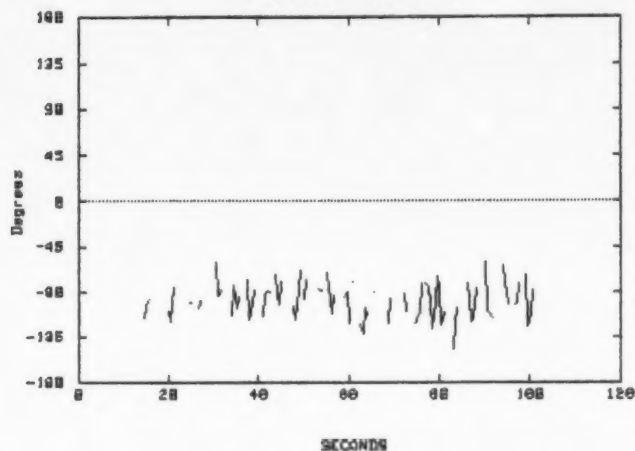
CW RUN B SEGMENT 1
X POSITION



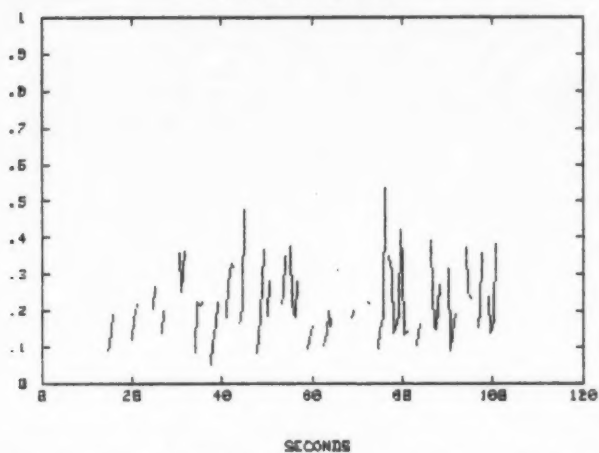
CW RUN B SEGMENT 1
Z POSITION



CW RUN 8 SEGMENT 2
FRICTION DIRECTION



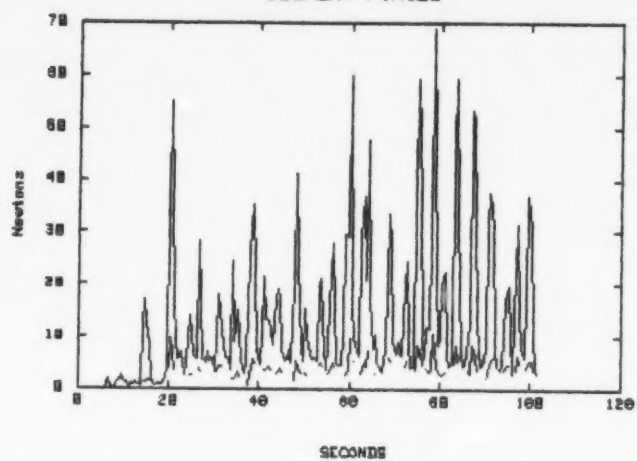
CW RUN 8 SEGMENT 2
FRICTION COEFF



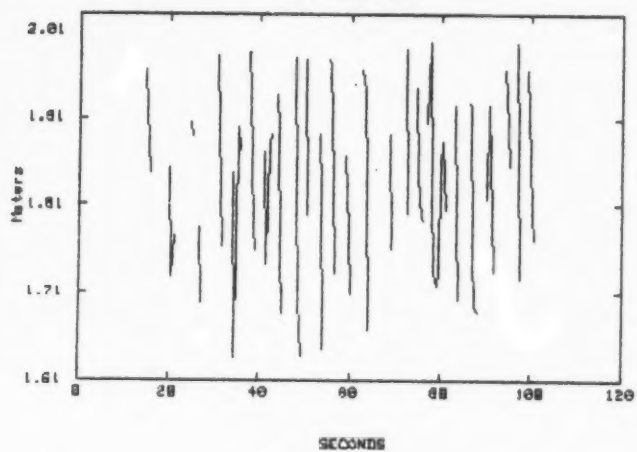
STATISTICS FOR INTERVAL FROM .52 TO 101.52 Seconds
 SAMPLES CALCULATED EVERY .498 SECS
 TEST CW RUN 8 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	15.007	STANDARD DEVIATION	13.361
AVERAGE X POSITION	1.840	STANDARD DEVIATION	.097
AVERAGE Z POSITION	.068	STANDARD DEVIATION	.027
AVERAGE FRICTION COEFF	.222	STANDARD DEVIATION	.100
PROJECTED FRICT. DIR.	-98.696	STANDARD DEVIATION	16.945
NUMBER OF DATA POINTS USED IN STATISTICS:		90	

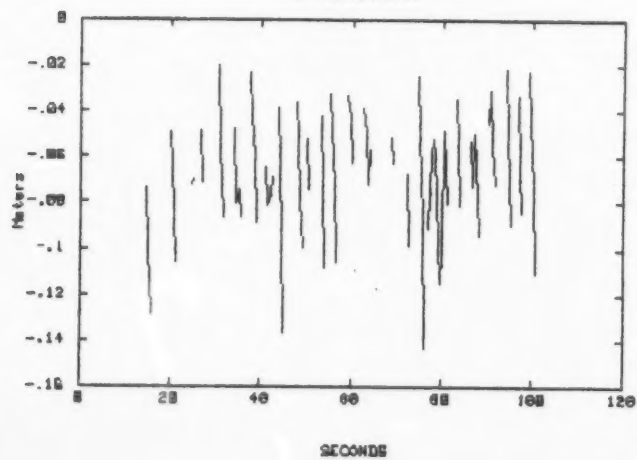
CW RUN B SEGMENT 2
SEGMENT FORCES



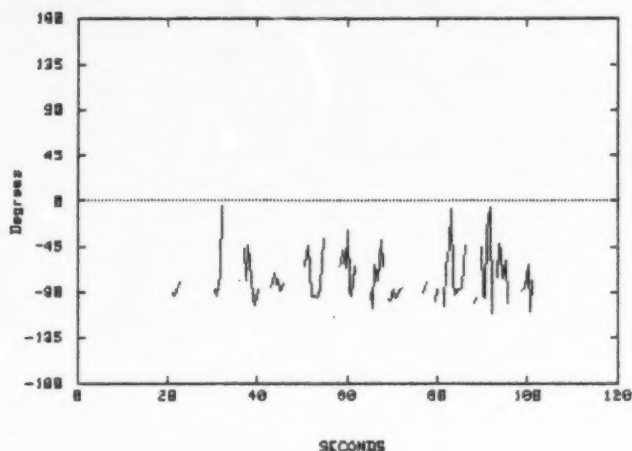
CW RUN B SEGMENT 2
X POSITION



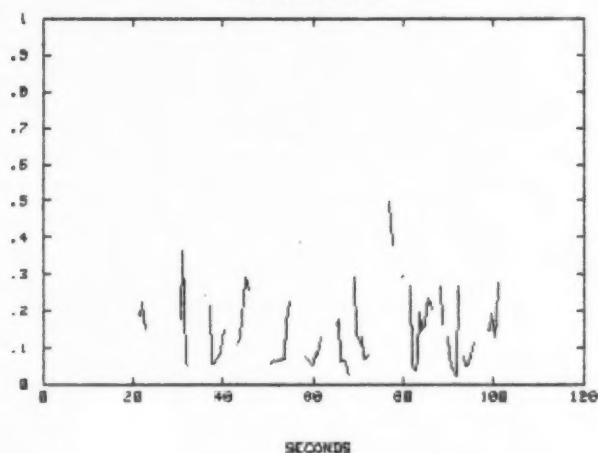
CW RUN B SEGMENT 2
Z POSITION



CW RUN B SEGMENT 3
FRICTION DIRECTION

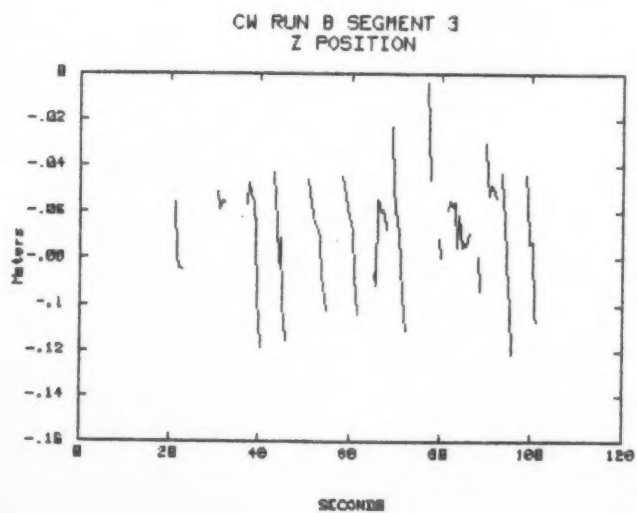
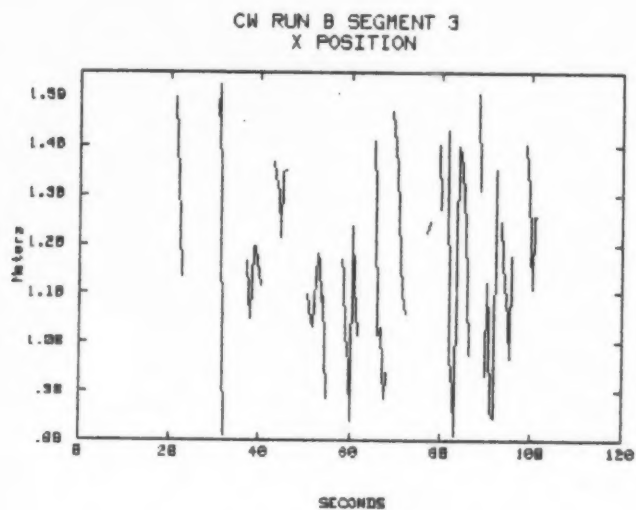
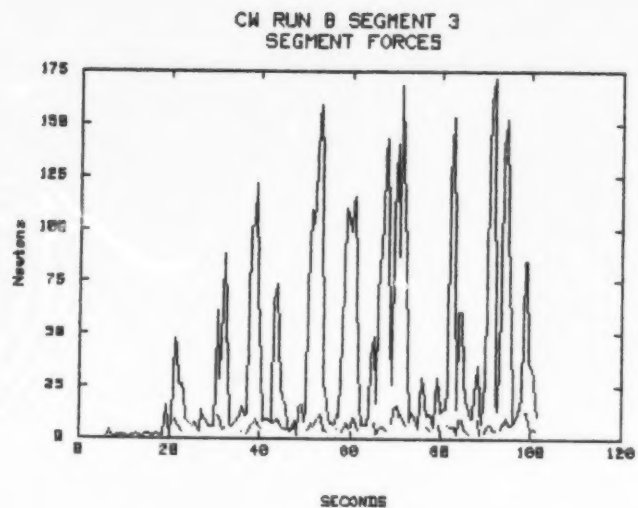


CW RUN B SEGMENT 3
FRICTION COEFF

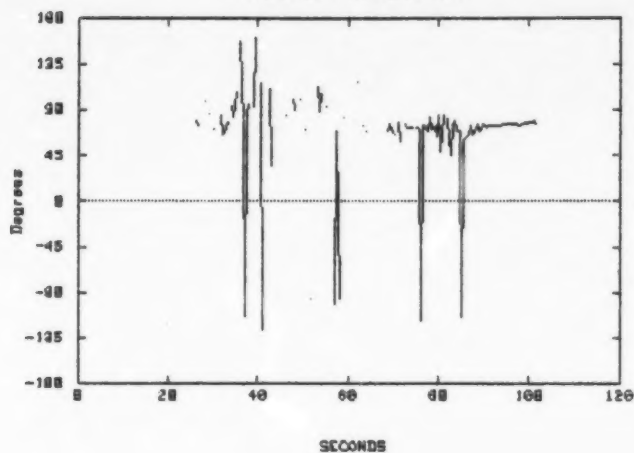


STATISTICS FOR INTERVAL FROM .52 TO 101.52 Seconds
 SAMPLES CALCULATED EVERY .498 SECS
 TEST CW RUN 8 DATE:
 SEGMENT 3

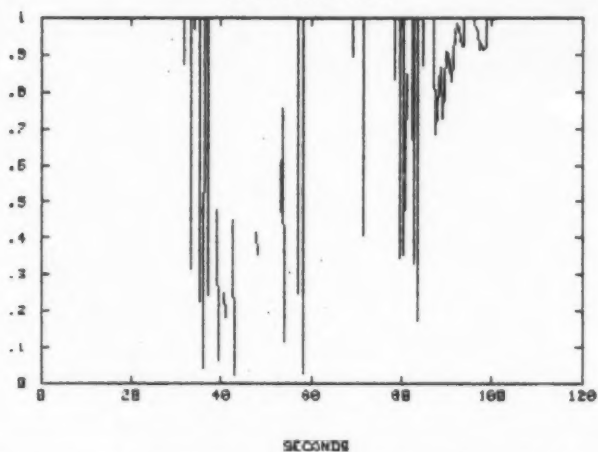
AVERAGE NORMAL FORCE	41.643	STANDARD DEVIATION	45.273
AVERAGE X POSITION	1.258	STANDARD DEVIATION	.183
AVERAGE Z POSITION	.068	STANDARD DEVIATION	.021
AVERAGE FRICTION COEFF	.143	STANDARD DEVIATION	.095
PROJECTED FRICT. DIR.	-76.079	STANDARD DEVIATION	23.558
NUMBER OF DATA POINTS USED IN STATISTICS:		88	



CW RUN 9 SEGMENT 1
FRICTION DIRECTION



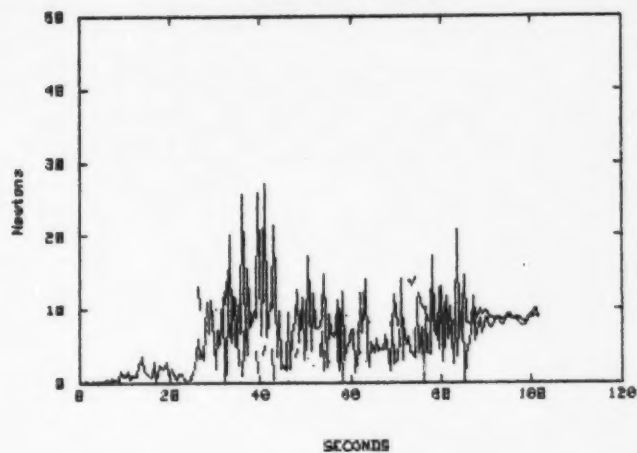
CW RUN 9 SEGMENT 1
FRICTION COEFF



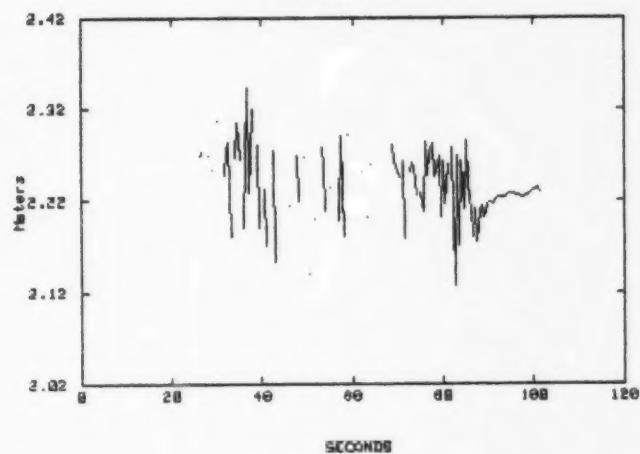
STATISTICS FOR INTERVAL FROM 25.00 TO 84.00 Seconds
 SAMPLES CALCULATED EVERY .498 SECS
 TEST CW RUN 9 DATE:
 SEGMENT 1

AVERAGE NORMAL FORCE	8.386	STANDARD DEVIATION	4.956
AVERAGE X POSITION	2.244	STANDARD DEVIATION	.043
AVERAGE Z POSITION	.053	STANDARD DEVIATION	.007
AVERAGE FRICTION COEFF	2.089	STANDARD DEVIATION	4.992
PROJECTED FRIC. DIR.	66.022	STANDARD DEVIATION	58.316
NUMBER OF DATA POINTS USED IN STATISTICS:		67	

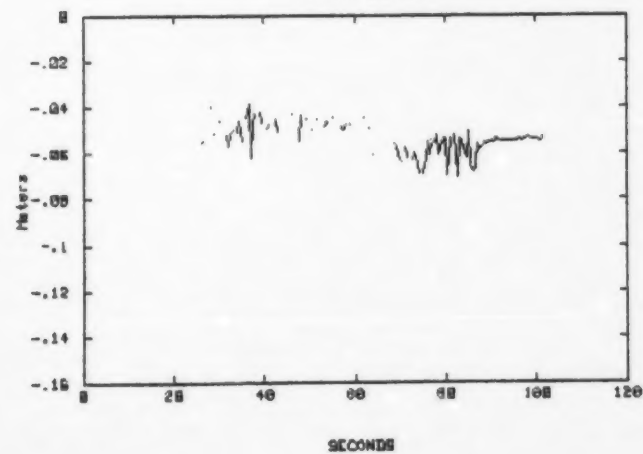
CW RUN 9 SEGMENT 1
SEGMENT FORCES



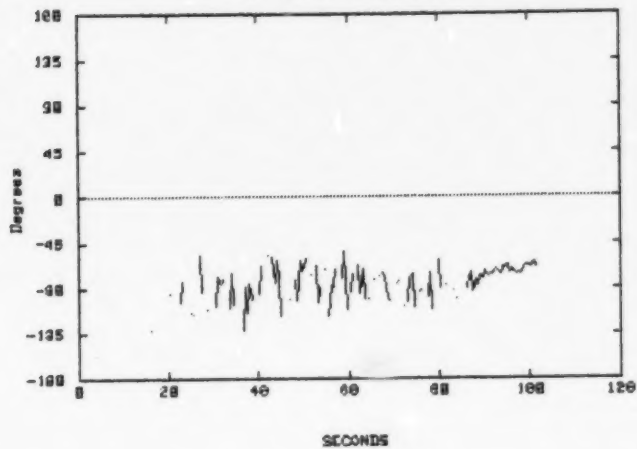
CW RUN 9 SEGMENT 1
X POSITION



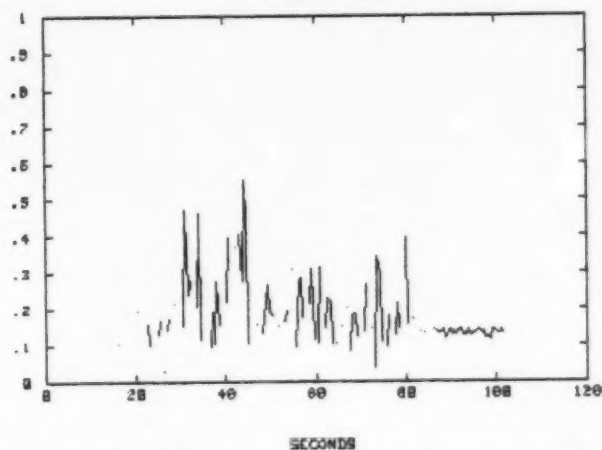
CW RUN 9 SEGMENT 1
Z POSITION



CW RUN 9 SEGMENT 2
FRICTION DIRECTION



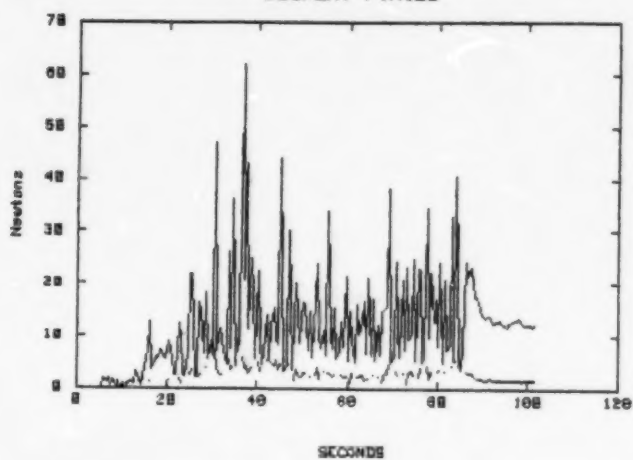
CW RUN 9 SEGMENT 2
FRICTION COEFF



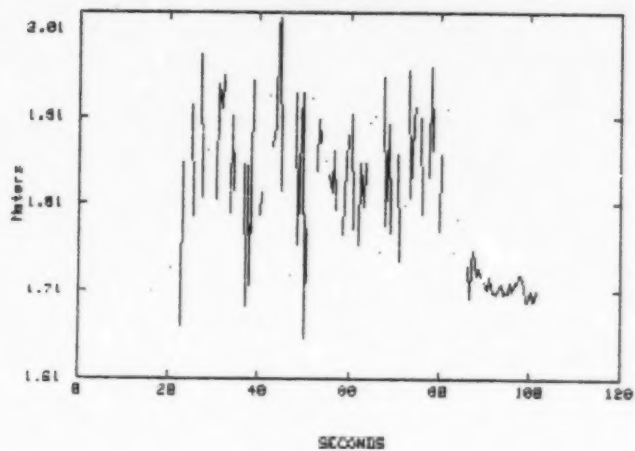
STATISTICS FOR INTERVAL FROM 25.00 TO 84.00 Seconds
 SAMPLES CALCULATED EVERY .498 SECS
 TEST CW RUN 9 DATE:
 SEGMENT 2

AVERAGE NORMAL FORCE	14.159	STANDARD DEVIATION	10.282
AVERAGE X POSITION	1.856	STANDARD DEVIATION	.076
AVERAGE Z POSITION	.049	STANDARD DEVIATION	.020
AVERAGE FRICTION COEFF	.210	STANDARD DEVIATION	.104
PROJECTED FRICT. DIR.	-88.025	STANDARD DEVIATION	17.502
NUMBER OF DATA POINTS USED IN STATISTICS:		73	

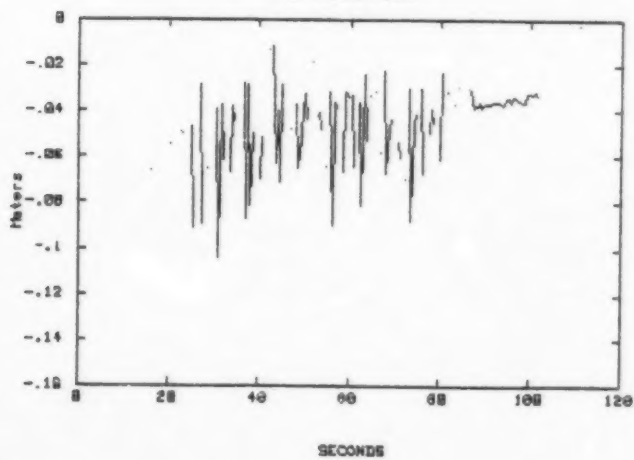
CW RUN 9 SEGMENT 2
SEGMENT FORCES



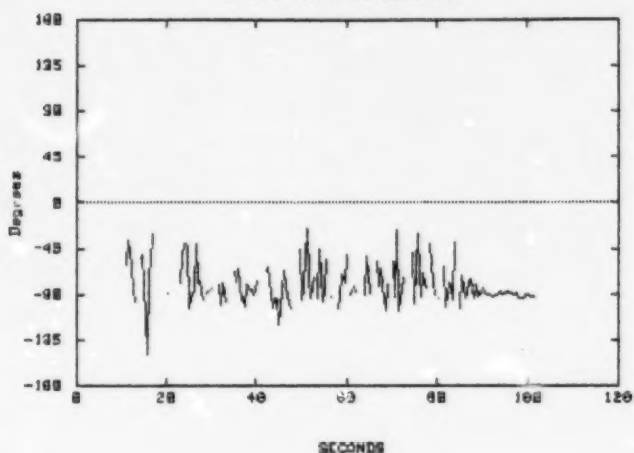
CW RUN 9 SEGMENT 2
X POSITION



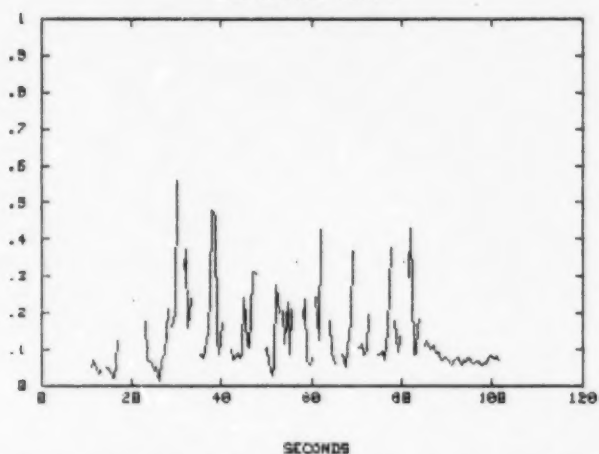
CW RUN 9 SEGMENT 2
Z POSITION



CW RUN 9 SEGMENT 3
FRICTION DIRECTION



CW RUN 9 SEGMENT 3
FRICTION COEFF

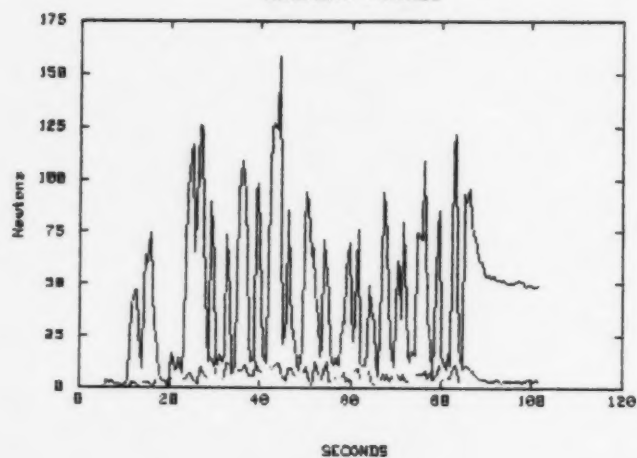


STATISTICS FOR INTERVAL FROM 25.00 TO 84.00 Seconds
SAMPLES CALCULATED EVERY .498 SECS

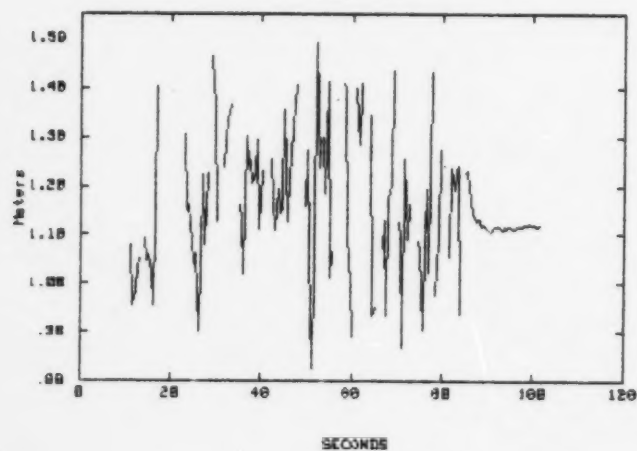
TEST CW RUN 9 DATE:
SEGMENT 3

AVERAGE NORMAL FORCE	48.962	STANDARD DEVIATION	37.238
AVERAGE X POSITION	1.261	STANDARD DEVIATION	.149
AVERAGE Z POSITION	.063	STANDARD DEVIATION	.021
AVERAGE FRICTION COEFF	.164	STANDARD DEVIATION	.114
PROJECTED FRICT. DIR.	-80.040	STANDARD DEVIATION	18.815
NUMBER OF DATA POINTS USED IN STATISTICS:		89	

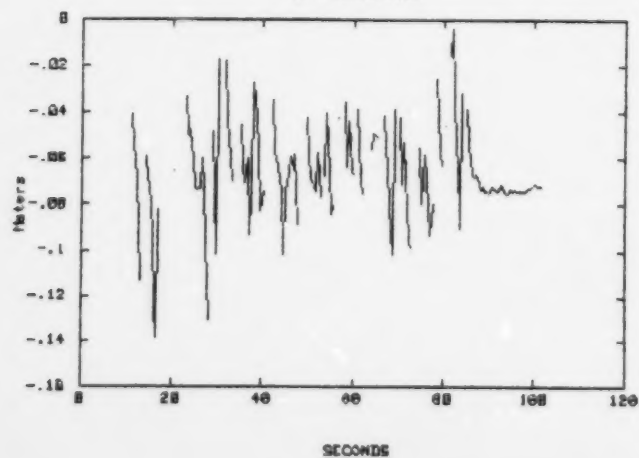
CW RUN 9 SEGMENT 3
SEGMENT FORCES



CW RUN 9 SEGMENT 3
X POSITION



CW RUN 9 SEGMENT 3
Z POSITION



APPENDIX K

NORMAL MAXIMA AND THEIR PARAMETER FROM TESTS CW5, CW9, S32

The values of the normal force maxima, the times at which they occurred and the values of x , z , α , β , F_f , μ and ψ at the normal force maxima are listed in table form for each segment during tests CW5, CW9 and S32. The values were chosen using the procedure discussed in Section 8, Volume I. The tables are given in the order of increasing segment number and in the test order of CW5, CW9 and S32. On the same page as each table is given the mean and standard deviation of the values are presented in the table. The particulars of each test are given below:

RUN	ICE THICKNESS	ICE STRENGTH	MODEL SPEED
	mm	kPa	m/s
CW5	27	25	0.14
CW9	48	30	0.22
S32	48	30	0.30



FILE NAME CWS MEAN CALCULATED OVER .049 SECS

TIME	NORMAL FORCE	LOCATION(M)		ANGLES		FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
		X	Z	ALPHA	BETA			
30.08	6.8	2.117	.052	32.1	55.3	.1	.01	-83.
31.26	6.5	2.183	.046	30.0	56.9	.4	.07	-115.
35.30	6.7	2.176	.043	29.9	56.2	3.5	.51	-116.
37.07	8.8	2.170	.040	30.0	55.6	4.4	.50	-120.
39.33	7.9	2.182	.041	29.6	56.1	3.5	.44	-118.
40.80	6.2	2.245	.032	28.7	50.8	3.8	.62	-126.
41.89	6.2	2.133	.046	31.4	55.4	1.9	.30	-114.
43.36	6.8	2.161	.047	30.9	56.3	.1	.02	103.
48.08	7.8	2.165	.042	30.2	55.8	2.2	.28	-119.
52.02	9.6	2.198	.038	29.1	56.0	3.0	.31	-115.
53.89	9.2	2.145	.046	31.2	55.8	2.2	.24	-112.
57.72	8.1	2.171	.048	30.7	56.8	.7	.08	43.
59.20	8.6	2.194	.043	29.1	56.8	5.2	.60	-114.

SEGMENT 1

STATISTICS FOR INTERVAL FROM 30.08 TO 59.20 Seconds

SAMPLES CALCULATED EVERY .098 SECS

TEST CW RUN 5 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	7.620	1.142
X POSITION	2.172	.031
Z POSITION	.043	.005
Alpha	30.221	.975
Beta	55.664	1.477
FRICTION COEFF	.307	.208
PROJECTED FRICT. DIR.	-85.191	69.033

FILE NAME CWS MEAN CALCULATED OVER .049 SECS

TIME	NORMAL FORCE	LOCATION(M)		ANGLES		FRICT. FORCE	FRICT. COEFF.	FRICT. PROJ	ANGLES
		X	Z	ALPHA	BETA				
30.67	16.8	1.828	.054	26.5	39.9	1.6	.10	-131.	
31.66	9.3	1.678	.048	21.8	32.1	1.5	.16	-83.	
32.74	12.3	1.750	.051	24.0	35.7	1.0	.08	-121.	
33.43	12.6	1.874	.052	28.2	42.0	.2	.02	-148.	
34.90	12.7	1.836	.049	26.5	39.7	.8	.06	-131.	
36.48	12.4	1.771	.056	24.9	37.4	.9	.07	-75.	
37.46	9.0	1.926	.055	30.2	45.5	1.1	.12	-99.	
37.95	10.3	1.814	.057	26.3	39.7	1.3	.13	-94.	
39.82	14.6	1.817	.055	26.2	39.5	1.1	.07	-107.	
40.80	8.5	1.929	.052	30.0	45.3	.7	.08	-72.	
41.59	11.2	1.809	.052	25.8	38.8	1.1	.10	-98.	
42.48	9.4	1.793	.056	25.6	38.5	1.4	.14	-72.	
43.75	12.2	1.799	.050	25.3	38.0	1.6	.13	-93.	
45.03	12.3	1.843	.051	26.9	40.4	.2	.02	-146.	
46.80	8.3	1.878	.050	28.2	42.0	.6	.08	-73.	
49.16	11.1	1.757	.053	24.3	36.4	1.4	.13	-85.	
50.05	15.9	1.827	.047	26.0	39.1	.8	.05	-100.	
51.62	8.5	1.911	.058	29.9	45.0	.7	.08	-116.	
52.80	10.8	1.850	.051	27.1	40.6	.7	.07	-119.	
53.20	13.4	1.781	.049	24.6	37.0	.8	.06	-101.	
54.28	13.9	1.853	.054	27.5	41.2	.7	.05	-64.	
54.97	14.5	1.750	.055	24.3	36.3	1.6	.11	-101.	
55.95	15.8	1.913	.052	29.6	44.3	1.5	.10	-119.	
57.23	10.9	1.973	.045	30.4	46.9	.3	.03	-54.	
58.21	17.3	1.801	.050	25.4	38.2	1.5	.08	-112.	
58.80	24.1	1.761	.054	24.5	36.7	1.9	.08	-127.	

SEGMENT 2

STATISTICS FOR INTERVAL FROM 30.67 TO 58.80 Seconds

SAMPLES CALCULATED EVERY .098 SECS

TEST CW RUN 5 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	12.614	3.432
X POSITION	1.828	.066
Z POSITION	.052	.003
Alpha	26.522	2.172
Beta	39.854	3.417
FRICTION COEFF	.084	.036
PROJECTED FRICT. DIR.	-101.535	24.465

FILE NAME CWS MEAN CALCULATED OVER .049 SECS

TIME	NORMAL FORCE	LOCATION(M) X	Z	ANGLES ALPHA BETA	FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
30.97	18.9	1.431	.040	12.6 20.1	2.0	.11	-69.
33.03	31.8	1.250	.044	8.5 14.2	3.2	.10	-57.
34.21	42.7	1.259	.069	9.5 16.4	2.1	.05	-86.
36.77	29.2	1.408	.052	12.5 20.2	4.3	.15	-81.
37.46	27.7	1.113	.050	5.7 12.0	3.8	.14	-23.
38.44	29.6	1.286	.054	9.6 15.8	2.9	.10	-60.
39.13	26.0	1.011	.040	3.3 9.7	4.0	.15	-25.
42.38	15.8	1.477	.034	13.8 21.5	2.8	.18	-89.
44.25	28.2	1.078	.054	5.0 11.6	3.7	.13	-22.
46.02	32.0	1.344	.051	10.8 17.2	3.1	.10	-63.
48.28	18.2	1.345	.035	10.1 15.9	1.4	.08	-40.
48.67	22.3	1.395	.039	11.5 18.5	2.8	.12	-81.
50.44	21.6	1.265	.056	9.2 15.5	1.6	.07	-64.
53.10	29.8	1.113	.048	5.6 11.9	2.1	.07	-47.
54.38	34.7	1.278	.065	9.9 16.6	3.6	.10	-51.
55.16	26.4	1.394	.060	12.5 20.5	1.3	.05	-72.
56.84	37.4	1.408	.054	12.6 20.5	3.7	.10	-81.
57.33	42.7	1.351	.049	10.9 17.4	4.1	.10	-69.
58.11	31.6	1.067	.055	4.8 11.4	2.1	.07	-38.

SEGMENT 3

STATISTICS FOR INTERVAL FROM 30.97 TO 58.11 Seconds

SAMPLES CALCULATED EVERY .098 SECS

TEST CW RUN 5 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	28.774	7.303
X POSITION	1.278	.136
Z POSITION	.050	.009
Alpha	9.382	3.038
Beta	16.144	3.483
FRICTION COEFF	.103	.034
PROJECTED FRICT. DIR.	-58.874	20.922

FILE NAME CW9 MEAN CALCULATED OVER .048 SECS

TIME	NORMAL FORCE	LOCATION(M) X Z	ANGLES ALPHA BETA	FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
31.56	16.0	2.217 .051	29.2 50.6	7.1	.45	82.
33.21	22.2	2.158 .056	31.8 56.9	5.9	.27	79.
34.18	17.9	2.198 .053	30.3 58.1	2.9	.16	68.
36.02	25.4	2.195 .044	29.1 56.9	.6	.02	163.
37.08	17.6	2.195 .063	31.9 59.1	4.7	.27	-110.
38.24	26.0	2.210 .049	29.1 51.3	3.8	.15	148.
39.60	23.3	2.169 .048	30.7 56.7	2.3	.10	-126.
40.85	31.0	2.218 .039	28.2 51.8	5.6	.18	123.
41.82	33.1	2.189 .044	29.4 56.7	1.5	.04	158.
42.98	20.9	2.163 .048	30.9 56.6	.9	.04	-97.
43.76	19.5	2.152 .051	31.5 56.4	.3	.02	-94.
45.89	15.0	2.212 .040	28.2 52.8	2.1	.14	93.
48.11	14.8	2.236 .041	26.7 46.1	4.8	.32	99.
50.44	19.7	2.172 .045	30.2 56.3	3.6	.18	81.
51.40	18.7	2.194 .041	28.9 56.5	1.2	.07	-141.
52.27	16.3	2.196 .043	28.9 56.8	1.8	.11	-110.
53.92	15.6	2.228 .043	27.1 46.4	4.4	.28	102.
54.89	15.5	2.186 .041	29.4 56.1	.3	.02	119.
57.98	13.8	2.199 .047	29.3 56.8	.6	.05	59.
59.15	12.1	2.170 .045	30.3 56.3	.6	.05	-18.

SEGMENT 1

STATISTICS FOR INTERVAL FROM 31.56 TO 59.15 Seconds

SAMPLES CALCULATED EVERY .097 SECS

TEST CW RUN 9 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	19.714	5.511
X POSITION	2.193	.023
Z POSITION	.047	.006
Alpha	29.553	1.394
Beta	54.757	3.590
FRICTION COEFF	.146	.116
PROJECTED FRICT. DIR.	33.789	103.597

FILE NAME CW9 MEAN CALCULATED OVER 0.000 SECS

TIME	NORMAL FORCE	LOCATION(M) X Z	ANGLES ALPHA BETA	FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
32.34	82.6	1.405 .050	12.3 20.0	11.5	.14	-88.
35.15	96.5	1.235 .051	8.4 14.5	9.1	.09	-73.
36.60	121.7	1.332 .063	11.0 17.8	10.5	.09	-93.
39.11	106.4	1.401 .064	12.9 21.2	14.9	.14	-89.
41.92	112.5	1.344 .032	10.0 15.6	10.0	.09	-68.
43.76	197.2	1.211 .072	8.5 15.7	14.2	.07	-103.
45.98	77.0	1.306 .057	10.1 16.4	8.1	.11	-68.
49.95	95.8	1.363 .057	11.5 18.7	10.4	.11	-96.
50.82	110.3	1.027 .071	4.1 11.4	4.6	.04	-77.
54.40	87.4	1.408 .062	13.0 21.2	12.1	.14	-88.
58.08	60.1	1.493 .038	14.5 22.6	8.2	.14	-99.
59.15	80.9	1.170 .046	6.8 12.9	4.7	.06	-79.

SEGMENT 3

STATISTICS FOR INTERVAL FROM 32.34 TO 59.15 Seconds

SAMPLES CALCULATED EVERY 0.000 SECS

TEST CW RUN 9 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	102.355	33.084
X POSITION	1.308	.122
Z POSITION	.055	.012
Alpha	10.261	2.814
Beta	17.323	3.362
FRICTION COEFF	.101	.032
PROJECTED FRICT. DIR.	-85.073	11.364

FILE NAME CW9 MEAN CALCULATED OVER 0.000 SECS

TIME	NORMAL FORCE	LOCATION(M) X Z	ANGLES ALPHA BETA	FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
30.60	46.9	1.810 .046	23.8 38.1	7.2	.15	-110.
31.85	18.9	1.914 .058	31.0 45.1	3.1	.16	-107.
33.50	29.2	1.788 .063	25.3 39.0	5.5	.19	-109.
34.37	37.7	1.887 .032	27.9 40.3	3.6	.10	-139.
36.50	54.6	1.863 .026	25.7 38.3	4.9	.09	-137.
37.66	49.1	1.854 .027	25.5 38.0	5.4	.11	-115.
38.73	40.2	1.794 .061	25.2 39.1	7.7	.19	-112.
39.79	44.0	1.813 .046	23.7 38.2	6.7	.15	-96.
41.34	47.8	1.770 .055	23.8 37.3	6.7	.14	-114.
42.21	17.1	1.952 .038	30.2 44.7	4.6	.27	-79.
43.27	22.9	1.920 .040	30.4 43.2	3.0	.13	-77.
45.11	66.2	1.796 .035	23.4 36.1	7.5	.11	-123.
46.95	34.2	1.739 .043	23.7 34.3	5.3	.15	-106.
48.40	28.0	1.809 .048	24.0 38.3	3.9	.14	-105.
50.73	22.5	1.836 .046	24.2 39.4	3.0	.13	-81.
52.85	34.2	1.906 .030	27.9 41.1	3.0	.09	-123.
54.11	24.8	1.718 .034	22.3 32.4	3.5	.14	-87.
55.56	38.2	1.840 .034	24.4 38.2	3.7	.10	-113.
56.92	24.5	1.761 .039	22.1 35.0	3.4	.14	-88.
58.37	17.1	1.873 .046	30.8 41.3	2.4	.14	-96.
59.53	21.1	1.885 .034	28.5 40.4	2.6	.12	-110.

SEGMENT 2

STATISTICS FOR INTERVAL FROM 30.60 TO 59.53 Seconds

SAMPLES CALCULATED EVERY 0.000 SECS

TEST CW RUN 9 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	34.747	13.214
X POSITION	1.835	.062
Z POSITION	.042	.011
Alpha	25.898	2.800
Beta	38.937	3.069
FRICTION COEFF	.140	.040
PROJECTED FRIC. DIR.	-106.079	16.765

FILE NAME S32 MEAN CALCULATED OVER .048 SECS

TIME	NORMAL FORCE	LOCATION(M)		ANGLES		FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
		X	Z	ALPHA	BETA			
30.21	37.3	2.200	.045	29.0	56.5	18.0	.48	-116.
30.89	25.1	2.245	.053	28.3	43.3	10.5	.42	-136.
31.95	21.9	2.331	.042	20.4	30.0	8.8	.40	159.
32.63	28.6	2.269	.041	24.7	37.6	10.5	.37	-150.
33.40	22.0	2.310	.045	22.9	30.0	11.1	.51	143.
34.37	24.6	2.239	.045	26.8	39.3	7.9	.32	-151.
35.05	19.7	2.183	.049	30.3	57.2	7.9	.40	-105.
36.11	20.9	2.194	.048	29.8	57.5	9.5	.45	-109.
38.24	17.4	2.267	.055	28.1	44.4	9.0	.52	-125.
39.89	24.1	2.224	.042	27.2	48.1	8.2	.34	-129.
40.56	24.7	2.186	.047	30.0	57.1	7.3	.29	-112.
41.05	25.2	2.182	.048	30.2	57.1	9.5	.38	-113.
42.02	17.4	2.234	.048	27.7	37.5	4.7	.27	-149.
42.98	24.2	2.201	.044	28.8	55.8	9.3	.38	-114.
43.76	21.6	2.240	.047	27.3	34.9	7.0	.32	156.
45.40	18.0	2.191	.046	29.6	57.1	3.1	.17	-94.
46.37	18.2	2.182	.049	30.4	57.3	9.4	.52	-103.
46.85	19.4	2.265	.044	25.2	30.0	5.8	.30	156.
47.73	28.0	2.185	.040	29.4	56.1	7.2	.26	-125.
48.40	22.6	2.176	.050	30.7	57.2	9.0	.40	-111.
48.98	16.2	2.228	.047	27.9	41.4	5.2	.32	-138.
50.05	24.6	2.193	.041	29.1	56.3	6.4	.26	-118.
50.53	23.8	2.201	.041	28.7	55.6	6.7	.28	-118.
51.40	26.6	2.192	.042	29.0	56.6	7.5	.28	-123.
52.85	14.9	2.240	.046	26.9	37.8	5.4	.36	-139.
53.34	15.8	2.276	.046	25.0	30.0	6.3	.40	156.
54.02	17.6	2.295	.042	22.7	30.0	6.4	.36	159.
54.69	18.0	2.261	.041	25.1	39.1	5.1	.28	-151.
55.76	19.0	2.280	.040	24.2	37.1	6.2	.33	-149.
56.82	25.9	2.201	.045	28.9	55.9	5.9	.23	-121.
57.98	27.4	2.190	.047	29.7	57.2	5.8	.21	90.
58.66	25.1	2.190	.050	30.1	57.6	2.7	.11	-108.

SEGMENT 1

STATISTICS FOR INTERVAL FROM 30.21 TO 58.66 Seconds

SAMPLES CALCULATED EVERY .097 SECS

TEST S3 RUN 2 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	22.373	4.645
X POSITION	2.227	.042
Z POSITION	.046	.004
Alpha	27.631	2.561
Beta	46.825	10.687
FRICITION COEFF	.341	.096
PROJECTED FRICT. DIR.	-65.324	112.993

FILE NAME S32 MEAN CALCULATED OVER .048 SECS

TIME	NORMAL FORCE	LOCATION(M) X Z	ANGLES ALPHA BETA	FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
30.40	27.8	1.933 .046	29.7 44.8	6.4	.23	-89.
30.98	27.5	1.935 .039	29.1 44.0	5.5	.20	-85.
31.47	61.9	1.740 .050	23.7 35.3	10.7	.17	-108.
31.95	37.8	1.764 .065	25.2 38.1	6.7	.18	-97.
33.40	64.8	1.778 .047	24.5 36.7	9.0	.14	-116.
33.89	32.9	1.974 .041	30.1 46.5	4.1	.13	-94.
35.34	59.0	1.846 .033	25.7 38.3	9.5	.16	-107.
36.02	26.4	1.940 .052	30.3 46.0	4.4	.17	-108.
36.60	39.2	1.824 .050	26.1 39.2	5.0	.13	-114.
37.18	48.7	1.817 .049	25.8 38.8	6.0	.12	-101.
38.34	24.4	1.827 .044	25.8 38.7	5.0	.20	-87.
39.40	37.6	1.793 .061	25.9 39.1	5.8	.15	-95.
40.66	52.7	1.855 .037	26.4 39.3	6.4	.12	-121.
41.44	33.9	1.823 .044	25.6 38.5	5.0	.15	-88.
42.40	43.2	1.772 .046	24.2 36.2	6.3	.14	-105.
43.27	34.2	1.897 .041	28.2 42.0	4.3	.13	-99.
44.15	23.5	1.835 .035	25.5 38.1	4.5	.19	-81.
44.63	38.0	1.891 .066	29.8 44.7	4.0	.11	-139.
45.79	49.4	1.781 .049	24.7 37.1	6.5	.13	-107.
46.37	26.5	1.932 .041	29.2 44.0	3.6	.14	-106.
46.95	34.8	1.719 .045	22.8 33.7	5.7	.16	-93.
47.92	28.8	1.933 .027	27.6 42.0	4.0	.14	-86.
48.40	24.4	1.800 .057	25.8 38.9	3.9	.16	-106.
49.47	54.9	1.787 .041	24.3 36.4	7.6	.14	-107.
50.05	31.3	1.911 .042	28.7 42.9	2.3	.08	-115.
50.73	35.9	1.862 .046	27.3 40.7	4.9	.14	-117.
51.50	28.5	1.858 .033	26.2 39.0	5.3	.19	-95.
52.18	46.1	1.736 .041	23.0 34.1	7.7	.17	-100.
53.34	41.8	1.880 .032	26.7 39.9	4.4	.11	-121.
54.98	35.1	1.867 .041	27.1 40.3	3.8	.11	-105.
55.76	34.4	1.753 .044	23.6 35.1	6.3	.18	-104.
56.24	38.2	1.895 .042	28.3 42.1	4.0	.10	-106.
57.21	39.9	1.809 .046	25.3 38.1	4.8	.12	-97.
58.37	31.7	1.820 .059	26.6 40.1	5.1	.16	-98.

SEGMENT 2

STATISTICS FOR INTERVAL FROM 30.40 TO 58.37 Seconds

SAMPLES CALCULATED EVERY .097 SECS

TEST S3 RUN 2 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	38.097	10.859
X POSITION	1.841	.066
Z POSITION	.045	.009
Alpha	26.436	2.047
Beta	39.658	3.265
FRICITION COEFF	.148	.033
PROJECTED FRICT. DIR.	-102.847	12.072

FILE NAME S32 MEAN CALCULATED OVER .048 SECS

TIME	NORMAL FORCE	LOCATION(M)		ANGLES		FRICT. FORCE	FRICT. COEFF.	FRICT. ANGLES PROJ
		X	Z	ALPHA	BETA			
30.50	96.2	.928	.047	1.6	8.4	12.4	.13	-30.
30.98	154.4	.921	.064	1.5	8.7	12.2	.08	-28.
31.66	165.3	1.288	.082	10.8	18.3	19.9	.12	-98.
32.24	89.8	1.006	.080	3.8	11.5	11.9	.13	-41.
34.66	150.2	1.323	.069	11.0	17.9	16.8	.11	-82.
35.53	86.7	1.246	.047	8.5	14.4	12.2	.14	-90.
37.76	132.1	1.275	.043	9.0	14.6	12.1	.09	.5.
38.05	153.1	1.160	.065	7.1	13.9	11.3	.07	-77.
38.73	149.7	1.207	.071	8.4	15.5	12.3	.08	-81.
39.98	66.4	1.432	.050	13.1	21.2	10.0	.15	-85.
41.44	71.3	1.343	.054	10.9	17.5	9.2	.13	-80.
42.02	103.1	1.273	.072	10.0	17.1	9.7	.09	-81.
43.27	36.3	1.406	.051	12.4	20.1	7.9	.22	-67.
44.15	43.9	1.564	.034	16.9	25.2	10.4	.24	-75.
45.40	79.0	1.142	.051	6.4	12.7	8.2	.10	-65.
45.89	120.8	1.112	.070	6.1	13.3	8.7	.07	-82.
47.15	97.7	1.244	.081	9.6	17.2	10.4	.11	-98.
48.60	135.5	1.333	.063	11.0	17.9	12.9	.10	-100.
49.27	109.0	1.035	.068	4.2	11.4	6.5	.06	-57.
50.82	70.8	1.396	.066	12.8	21.1	11.9	.17	-99.
52.37	49.5	1.570	.063	18.7	28.9	13.9	.28	-93.
54.21	79.3	1.033	.054	4.0	10.6	7.2	.09	-44.
54.79	86.9	1.018	.068	3.8	11.1	6.0	.07	-71.
57.21	81.2	1.316	.064	10.7	17.3	7.5	.09	-75.

SEGMENT 3

STATISTICS FOR INTERVAL FROM 30.50 TO 57.21 Seconds

SAMPLES CALCULATED EVERY .097 SECS

TEST S3 RUN 2 DATE:

	MEAN	STANDARD DEV.
NORMAL FORCE	100.334	36.568
X POSITION	1.232	.178
Z POSITION	.062	.012
Alpha	8.845	4.342
Beta	16.071	4.882
FRICTION COEFF	.122	.054
PROJECTED FRICT. DIR.	-74.404	20.416